(10) For the use of other Mannich intermediates with ketones see: (a) A. Ahond, A. Cave, C. Kan-Fan, and P. Poitiers, *Bull. Soc. Chim. Fr.*, 2707 (1970); (b) Y. Jason, M. J. Luche, M. Gaudry, and A. Marquet, *J. Chem. Soc., Chem. Commun.*, 253 (1974); (c) G. Kinast and L. F. Tietze, *Angew. Chem., Int. Ed. Engl.*, **15**, 239 (1976).

(11) J. Schreiber, M. Haag, N. Hashimoto, and A. Eschenmoser, *Angew. Chem., Int. Ed. Engl.*, **10**, 330 (1971). The use of this agent for lactone methylenation was first suggested to us by Professor Paul Dowd of the University of Pittsburgh.

(12) For a somewhat analogous reaction with enol borinates see: J. Hooz and J. N. Bridson, *J. Am. Chem. Soc.*, **95**, 603 (1973). Since enol borinates and trimethylsilyl enol ethers are prepared from totally different types of precursors, our results, together with those of Hooz, provide enormous flexibility in regiospecific control over the Mannich reaction from various ketonic precursors.

(13) For regiospecific introduction of Mannich bases via β-keto esters and β-keto acids see: R. B. Miller and B. F. Smith, *Tetrahedron Lett.*, 5037 (1973) and ref 15a.

(14) G. Stork and J. Singh, *J. Am. Chem. Soc.*, **96**, 6181 (1974); (B) J. E. McMurray, *ibid.*, **90**, 6821 (1968).

(15) (a) R. A. Micheli, Z. G. Hajos, N. Cohen, D. R. Parrish, L. A. Portland, W. Sciammanna, and P. A. Wehrli, *J. Org. Chem.*, **40**, 675 (1975); (b) G. Stork and J. D'Angelo, *J. Am. Chem. Soc.*, **96**, 7114 (1974); (c) S. Danishefsky and T. Kitahara, *ibid.*, **96**, 7807 (1974).

(16) The structure of this compound is in accord with (a) its infrared, NMR and mass spectra; (b) its combustion analysis.

(17) M. S. Newman and C. A. Vander Werf, *J. Am. Chem. Soc.*, **67**, 233 (1945). For a recent synthesis see: S. Danishefsky, T. Kitahara, M. Tsai, and J. Dynak, *J. Org. Chem.*, **41**, 1669 (1976).

(18) The starting material which we used was prepared (53%) by a Wittig reaction on the corresponding angular formyl compound: see S. Danihsefsky, P. F. Schuda, and K. Kato, *J. Org. Chem.*, **41**, 1081 (1976). For previous synthesis of **22** and **23** see ref 19, 20 (clearly the method of choice for **22**), and 21.

19. P. A. Grieco, K. Hiroi, J. J. Reap, and J. A. Noquez, *J. Org. Chem.*, **40**, 1450 (1975).

(20) R. D. Clark and C. A. Heathcock, *J. Org. Chem.*, **41**, 1396 (1976).

(21) J. A. Marshall and D. E. Seitz, *J. Org. Chem.*, **40**, 534 (1975).

(22) Prepared by Mei-Yuan Tsai of this Laboratory: S. Danishefsky, M. Tsai, and T. Kitahara, manuscript in preparation.

(23) In several cases it was shown that the hydroxyl group is not liberated until aqueous acid workup. We have not yet properly investigated the status of this oxygen or the precise nature of the functional group (or mixtures of systems) which is present after the methyl iodide–DBU sequence. Conceivably, a fuller understanding of this situation might allow for yield improvements in the unprotected α-hydroxy series.

(24) This reaction was conducted once on 28 mg of **2**. Thus, the rather disappointing yield reported here may well be subject to improvement. Such efforts will be made.

(25) Since the overall yields are quite low, it need not follow that the major compound of the **3**, **4** mixture arises from the major component of its precursor **1**, **2** mixture.

Samuel Danishefsky,* Takeshi Kitahara
Robert McKee, Paul F. Schuda
Department of Chemistry, University of Pittsburgh
Pittsburgh, Pennsylvania 15260

Received May 24, 1976

Synthetic Methods and Reactions. 17.[1] Uranium Hexafluoride, a Convenient New Oxidizing Agent for Organic Synthesis

Sir:

Uranium hexafluoride, depleted of fissionable ^{235}U, is abundantly available.[2] In spite of its availability and remarkable properties, the study of the reactions of UF_6 with organic compounds remained virtually unexplored. The highly covalent nature of UF_6 makes it particularly suitable for reaction in nonaqueous solvents. Stable solutions of UF_6 in chlorofluorocarbons (Freons) or chlorohydrocarbons (methylene chloride or chloroform), can be used conveniently as they do not attack glass and are generally easy to handle. We wish to report our observation of the facile and selective oxidation of several classes of organic compounds with UF_6, which promises to make it a useful oxidizing agent in organic synthesis.

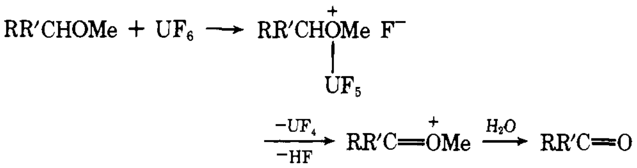
Ethers undergo oxidative cleavage to form carbonyl compounds and alcohols. Furthermore, the direction of cleavage is predictable, thus the utility of ethers (such as benzyl or benzhydryl ethers) as protecting groups for alcohols is broadened. The oxidation of methyl ethers is regiospecific. Trapping experiments with phenyllithium suggest the intermediacy of methoxycarbenium ions in the reaction. Results of the oxidation of alkyl (cycloalkyl) methyl ethers are summarized in Table I.

Table I. Oxidative Cleavage of Alkyl (Cycloalkyl) Methyl Ethers

Alkyl (cycloalkyl) methyl ether	Carbonyl product	Yield, %
Cyclohexyl	Cyclohexanone	86
Cycloheptyl	Cycloheptanone	83
Benzyl	Benzaldehyde	78
p-Tolyl	4-Tolualdehyde	73
4-Bromobenzyl	4-Bromobenzoaldehyde	67
Benzhydryl	Benzophenone	57
4-Nitrobenzyl	4-Nitrobenzaldehyde	77
4-Cyanobenzyl	4-Cyanobenzaldehyde	71
α-Phenethyl	Acetophenone	75

Table II. Oxidative Cleavage of Benzyl and Benzhydryl Ethers

Ether	Alcohol product	Yield, %
n-Hexyl benzyl	*n*-Hexanol	44
Cyclohexyl benzyl	Cyclohexanol	66
Cycloheptyl benzyl	Cycloheptanol	56
n-Octyl benzhydryl	*n*-Octanol	63
Cyclohexyl benzhydryl	Cyclohexanol	61
2-Octyl benzhydryl	2-Octanol	69
2-*o*-Nitrophenethyl benzhydryl	2-*o*-Nitrophenethyl alcohol	64



$$\mathrm{RR'CHOMe} + \mathrm{UF_6} \longrightarrow \mathrm{RR'CH}\underset{\mathrm{UF_5}}{\overset{+}{\mathrm{O}}}\mathrm{Me}\ \mathrm{F^-} \xrightarrow[-\mathrm{HF}]{-\mathrm{UF_4}} \mathrm{RR'C{=}\overset{+}{O}Me} \xrightarrow{\mathrm{H_2O}} \mathrm{RR'C{=}O}$$

Benzyl and benzhydryl ethers are cleaved to the corresponding alcohols and benzaldehyde or benzophenone, respectively. The usefulness of the present method is further demonstrated by the cleavage of 2-*o*-nitrophenethyl benzhydryl ether to benzophenone and the parent alcohol by UF_6. Hydrogenolytic procedures would be untenable due to the presence of an easily reducible nitro group. No attempt has been made to optimize yields of the products summarized in Table II, which clearly can be improved.

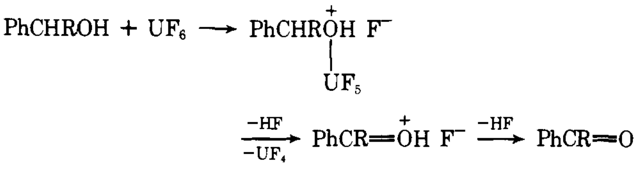
$$\mathrm{ROCHR'Ph} \xrightarrow[2.\ \mathrm{H_2O}]{1.\ \mathrm{UF_6}} \mathrm{ROH} + \mathrm{PhR'CO}$$

$$\mathrm{R} = \text{alkyl, cycloalkyl}$$

$$\mathrm{R'} = \mathrm{H} \text{ or } \mathrm{Ph}$$

In a typical procedure for the oxidative cleavage of ethers, an ice-cooled magnetically stirred solution of 3.52 g (0.01 mol) of UF_6 in 100 ml of 1,1,2-trichlorotrifluoroethane (Freon 113) was reacted with 1.28 g (0.01 mol) of cycloheptyl methyl ether, added dropwise in 10 ml of the same solvent. The reaction was allowed to proceed for 1 h and was quenched with 25 ml of water and the resulting uranyl salts were filtered. The filtrate was worked up in the usual manner to give 0.93 g (83% yield) of pure cycloheptanone, characterized as the 2,4-dinitrophenylhydrazone (mp 145 °C).

Benzylic alcohols are readily oxidized to the corresponding



$$\mathrm{PhCHROH} + \mathrm{UF_6} \longrightarrow \mathrm{PhCHR}\underset{\mathrm{UF_5}}{\overset{+}{\mathrm{O}}}\mathrm{H}\ \mathrm{F^-} \xrightarrow[-\mathrm{UF_4}]{-\mathrm{HF}} \mathrm{PhCR{=}\overset{+}{O}H}\ \mathrm{F^-} \xrightarrow{-\mathrm{HF}} \mathrm{PhCR{=}O}$$

Table III. Oxidation and Oxidative Fluorination of Alcohols and Aldehydes

Alcohol or aldehyde	Products	Yield, %
Benzyl	Benzaldehyde (benzoyl fluoride)	40
4-Methylbenzyl	*p*-Tolualdehyde (*p*-toluoyl fluoride)	38
1-(4-Fluorophenyl)ethanol	4-Fluoroacetophenone	64
Benzhydryl	Benzophenone	45
Benzaldehyde	Benzoyl fluoride	40
Heptanal	Heptanoyl fluoride	47
Pentanal	Pentanoyl fluoride	29
2-Bromobenzaldehyde	2-Bromobenzoyl fluoride	35

Table IV. Oxidative Cleavage of Hydrazones

Carbonyl product	Yield, %
N,N-Dimethylhydrazone	
Propiophenone	49
Cyclohexanone	46
4-*tert*-Butylcyclohexanone	50
2-Heptanone	56
2-Methylcyclohexanone	69
Benzaldehyde	41
Tosylhydrazone	
Acetophenone	96
Isobutyrophenone	95
Cycloheptanone	95
Cyclooctanone	76
2-Norbornanone	56
4-Heptanone	66

carbonyl compounds. In the case of aldehydes transformation into aroyl fluorides can also take

$$RCHO + UF_6 \rightarrow RCHO^{+}{-}UF_5\ F^{-} \xrightarrow[-UF_4]{-HF} RCOF$$

place with excess UF_6. Oxidative fluorination of aliphatic and aromatic aldehydes with UF_6 to the corresponding acyl fluorides indeed can be carried out as a general reaction. The results of the reaction of benzylic alcohols and aliphatic, as well as aromatic aldehydes are summarized in Table III.

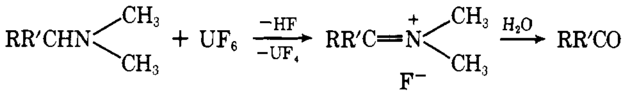
Oxidative cleavage of protected carbonyl compounds, such as tosylhydrazones and *N,N*-dimethylhydrazones, also takes place with ease upon aqueous quenching of the initially formed UF_6 adducts.

$$RR_1C{=}NN(CH_3)_2 \xrightarrow[2.\ H_2O]{1.\ UF_6} RR_1C{=}O$$

Data of the studied hydrazones are summarized in Table IV.

The oxidation of carboxylic acid hydrazides with UF_6 appears to be more complex, as the corresponding acids were isolated in only fair yield (benzoic acid 30%, *m*-nitrobenzoic acid 25%, phenylacetic acid 34%, and cyclohexanecarboxylic acid 55%).

N,N-Dimethylalkyl(cycloalkyl)amines are also oxidized by UF_6, yielding on aqueous quench the corresponding carbonyl compounds in fair yield. We are presently extending our



$$RR'CHN(CH_3)_2 + UF_6 \xrightarrow[-UF_4]{-HF} RR'C{=}\overset{+}{N}(CH_3)_2\ F^{-} \xrightarrow{H_2O} RR'CO$$

investigation of the utility of UF_6 in oxidizing such varied organic systems as benzoins, hydroquinones, aromatic hydrocarbons, epoxides, alkenes, sulfur compounds, and the like.

Our studies have shown that UF_6 is a new, convenient oxidizing agent for organic synthesis. The surprisingly limited fluorinating ability of UF_6 in solution does not interfere with most reactions. In addition, many organic functional groups are unaffected under our reaction conditions. These include, inter alia, ketone, ester, amide, nitrile, and nitro groups.

Acknowledgments. Partial support of our research by the National Science Foundation is gratefully acknowledged.

References and Notes

(1) Part 16. G. A. Olah, H. C. Lin, and A. Serianz, *Synthesis*, 42 (1976).

(2) UF_6 was obtained from the U.S. Energy Research and Development Administration in its depleted form. This material can be safely handled with normal laboratory techniques and care, considering its ease of hydrolysis giving hydrogen fluoride, and its low radioactivity.

George A. Olah,* John Welch, Tse-Lok Ho
Department of Chemistry, Case Western Reserve University
Cleveland, Ohio 44106

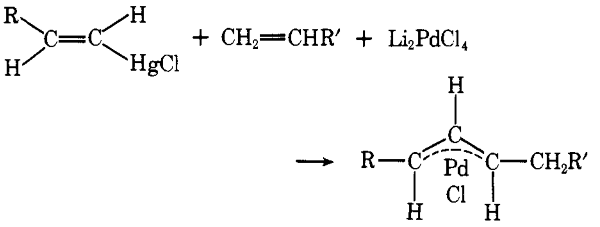
Received May 10, 1976

Mercury in Organic Chemistry. 9. A Novel Synthesis of π-Allylpalladium Compounds

Sir:

π-Allylpalladium compounds have been known since 1957.[1] They have recently found increasing utility in organic synthesis due to the ease with which they undergo stereocontrolled carbon-carbon bond formation.[2] Today the most widely employed methods of preparing these compounds involve either the direct allylic hydrogen substitution of alkenes[3,4] or palladium insertion into allylic halides.[5,6] We wish to report a novel new route to π-allylpalladium compounds which has a number of advantages over previous methods.

During studies directed towards the development of new synthetic methods employing organomercurials, we chose to examine the reaction of vinylmercuric chlorides, palladium salts, and simple alkenes. It was anticipated that conjugated 1,3-dienes would be obtained in a fashion similar to that previously reported.[7] To our surprise we obtained excellent yields of π-allylpalladium compounds instead (eq 1). An examination



(1)

of Table I indicates the full scope of this reaction. Excellent yields are obtained from vinylmercurials derived from both internal and terminal acetylenes.[8,9] Especially rewarding is the ability of the reaction to accommodate not only simple olefins such as ethylene and 1-hexene, but a wide variety of functionally substituted olefins including α,β-unsaturated esters, nitriles, and ketones. Internal olefins also undergo reaction, although the yield decreases with increasing substitution.

The following procedure for the preparation of di-μ-chlorodi(1-carboethoxy-5,5-dimethylhex-2-enyl)dipalladium(II) (entry 3) is representative. Anhydrous lithium chloride (20 mmol) and palladium chloride (10 mmol) were added to a well-dried round-bottom flask containing a nitrogen inlet tube and septum inlet. After flushing with nitrogen, 100 ml of tetrahydrofuran (THF) and 10 g of ethyl acrylate (100 mmol) were added by syringe. After cooling to 0 °C, 3.19 g of *trans*-3,3-dimethyl-1-butenylmercuric chloride (10 mmol) was added while backflushing with nitrogen. The well-stirred reaction