0.5-ml samples of the reaction mixture were withdrawn from the tube by means of a long-needle hypodermic syringe inserted through the serum cap, quenched by cooling to liquid nitrogen temperature, and then analyzed by glc immediately. The reaction was followed quantitatively by measuring the relative area ratio of both the reactant and product *vs.* the internal standard. The time of reaction was measured from the beginning of shaking to the instant of quenching. Rate constants were calculated from 9 to 13 separate determinations of concentrations in the region 10–85% reaction. Control experiments indicated that iodomethane was not reactive toward the phosphonites under conditions of glc analysis and that the internal standard was inert toward the reactants under all circumstances. The products were stable and were isolated from glc and identified.

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Thallium in Organic Synthesis. XXXII. Oxidative Rearrangement of Olefins Using Thallium(III) Nitrate (TTN)[1-3]

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Abstract: Thallium(III) nitrate (TTN) effects rapid rearrangement of olefins to carbonyl compounds. Examination of other thallium(III) salts has shown that some control over the reaction pathway can be achieved by varying the nature of the associated anion and the reaction conditions. The scope, limitations, and synthetic utility of TTN oxidations of olefins are defined.

Although oxidation of unsaturated systems with electrophilic metal salts is of long established synthetic and mechanistic interest, the majority of these processes are unique with respect to both oxidant and substrate, and meaningful correlations on the relative reactivities of metal salts are disappointingly few. The most notable exceptions are metalation and oxymetalation reactions.[5,6] Both processes have long been known with mercury(II) salts, and there are now examples of metalation and/or oxymetalation reactions with lead(IV), thallium(III), palladium(II), platinum(II), gold(III), and, possibly, rhodium(III) salts.[5,6] These reactions thus appear to be characteristic of metal ions which can be regarded as "soft"[7] or as having "class b"[8] character. Within this general context the reactions of unsaturated, nonaromatic substrates with the isoelectronic salts of mercury(II), thallium(III), and lead(IV) are of particular interest. The oxidation potentials of the ions are in the order Hg < Tl < Pb; two comparative studies of oxymetalation of olefins with the acetates of the three metals have established the intermediate position of the thallium salt.[9,10] In this and subsequent papers we describe the results of our investigations on oxythallation reactions with particular emphasis on the use of thallium(III) nitrate (TTN) as oxidant.

Oxidation of olefins with mercury(II), thallium(III), or lead(IV) salts can lead to a variety of products depending on the nature of the metal cation, the anion, the solvent, and the structure of the olefin. Oxymercuration with mercury(II) acetate has been extensively investigated,[6] and the synthetic scope of mercury(II) salt oxidation has been recently reviewed[11] and further extended by the introduction of mercury(II) trifluoroacetate[12] and nitrate.[13] The analogous reactions with thallium(III)[6,14] and lead(IV)[6,15] acetate have been studied much less comprehensively, and in contrast to oxymercuration there are few synthetically useful procedures based on oxythallation or oxyplumbation. Thus, treatment of olefins with lead(IV) acetate generally gives complex mixtures of products,[15] while stable oxymercuration adducts are formed with mercury(II) salts.[6] Oxythallation adducts have been isolated only occasionally,[9,16-18] and a variety of products derived by subsequent decomposition of the oxythallation adducts may be formed.[9,10,14,18-27]

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(1) Part XXXI: A. McKillop, R. A. Raphael, and E. C. Taylor, *J. Org. Chem.*, 37, 4204 (1972).

(2) We gratefully acknowledge partial financial support of this work by Eli Lilly and Co., the Ciba Pharmaceutical Co., and G. D. Searle and Co.

(3) Preliminary communication: A. McKillop, J. D. Hunt, E. C. Taylor, and F. Kienzle, *Tetrahedron Lett.*, 5275 (1970).

(4) (a) University of East Anglia; (b) Princeton University; (c) NRCC Postdoctoral Fellow, 1968–1970.

(5) W. Kitching, *Organometal. Chem. Rev.*, 3, 35 (1968).

(6) W. Kitching, *ibid.*, 3, 61 (1968).

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(11) H. Arzoumanian and J. Metzger, *Synthesis*, 527 (1971).

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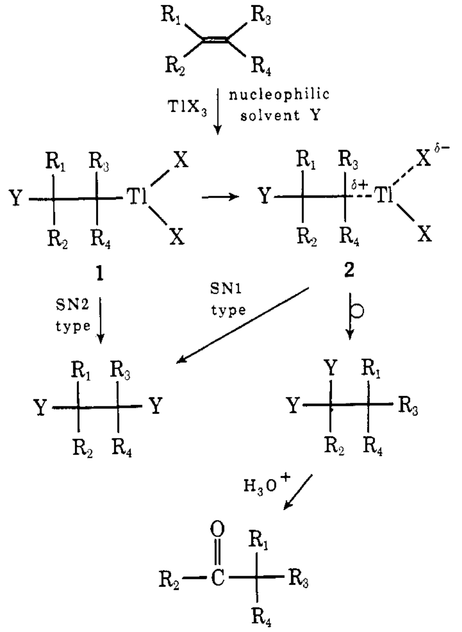
(21) W. D. Ollis, K. L. Ormand, and I. O. Sutherland, *J. Chem. Soc. C*, 119 (1970).

Two types of product generally predominate in these oxythallation reactions, namely glycols (or their derivatives) (50–60%) and aldehydes or ketones (or their acetals or ketals) (30–40%).[28] The mechanisms leading to these products are outlined in Scheme I. Alkylthallium(III) compounds (*e.g.*, **1**) are extremely unstable,[29] and C–Tl bond heterolysis is known to proceed *via* a transition state approaching carbonium ion character (*e.g.*, **2**).[30] Subsequent reaction may then lead either to glycol or to carbonyl derivatives. Formation of the latter products necessitates a Wagner–Meerwein type of rearrangement, probably *via* the carbonium ion species **2**; glycols, on the other hand, may arise from either **1** or **2**. Assuming that the rate of SN2 type displacement from **1** by the solvent does not vary substantially with the nature of X, the rate of progression from **1** to **2** should be a function of the ease of heterolysis of the C–Tl bond; that is, carbonium ion intermediates should be formed most rapidly from highly ionic compounds, $RTlX^+ X^-$.

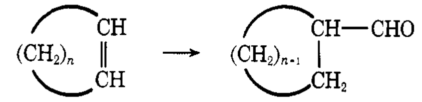
Scheme I



No data are available which indicate the degree of ionic character in alkylthallium(III) compounds. Conductance measurements in methanol on the more stable arylthallium(III) derivatives, however, have shown that when X = Cl^- or CH_3COO^- the compounds are only partially ionized, while when X = CF_3COO^- they are 1:1 electrolytes.[31] If the relative ionic character of alkylthallium(III) salts is in the same order, carbonium ion intermediates should be formed more rapidly from heterolysis of alkylthallium ditrifluoroacetates than from the corresponding acetates,[32] and thallium(III) trifluoroacetate (TTFA)[35] should thus be a more effective reagent for oxidative rearrangement of olefins (see Scheme I) than thallium(III) acetate.

TTFA, developed as a specific reagent for electrophilic aromatic thallation,[36,37] is a highly ionic salt.[38] Comparison of the oxidation of cyclohexene by TTFA in trifluoroacetic acid (TFA) with that by thallium(III) acetate in acetic acid[10] confirms the rate enhancement possible in oxythallation reactions when a highly ionic reagent is employed. Although approximately the same mixture of product types was obtained, oxidation by TTFA is complete within 10 min at room temperature, whereas the reaction with thallium(III) acetate requires 13 hr.[39] Data for the ring contraction of a variety of cyclic olefins with TTFA–ether are listed in Table I.

Table I. Ring Contraction of Cyclic Olefins with TTFA–Ether



Olefin	% ring contraction[a]
Cyclohexene	66
3-Methylcyclohexene	57
Cycloheptene	35
Cyclooctene	16
5α-Cholest-2-ene	15[b]

[a] The aldehydes were isolated as the 2,4-dinitrophenylhydrazone derivatives. [b] Isolated by oxidation of the initial aldehyde to the carboxylic acid.

For ring contractions of cyclic olefins, the data in Table I establish the superiority of TTFA over thallium(III) acetate. However, yields are, at best, only moderate and the ease with which TTFA attacks many types of functional groups limits the number of useful solvents.

Thallium(III) nitrate (TTN), which is almost completely ionic,[40] proved to be even more effective. TTN is readily obtained as the trihydrate in excellent yield

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(22) W. D. Ollis, K. L. Ormand, B. T. Redman, R. J. Roberts, and I. O. Sutherland, *J. Chem. Soc. C*, 125 (1970).

(23) R. J. Ouellette, G. Kordosky, C. Levin, and S. Williams, *J. Org. Chem.*, **34**, 4104 (1969).

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(25) R. M. Moriarty and H. Gopal, *Tetrahedron Lett.*, 347 (1972).

(26) L. Farkas, A. Gottsegen, M. Nogradi, and S. Antus, *J. Chem. Soc., Chem. Commun.*, 825 (1972).

(27) S. Uemura, A. Tabata, M. Okana, and K. Ichikawa, *Chem. Commun.*, 1630 (1970).

(28) It has been shown recently that oxidation of certain simple olefins with thallium(III) acetate under carefully controlled conditions in a three component solvent system can result in formation of epoxides in high yield (see ref 18).

(29) A. G. Lee, "The Chemistry of Thallium," Elsevier, London, 1971, pp 213–238.

(30) W. Kitching, *Rev. Pure Appl. Chem.*, **19**, 1 (1969).

(31) A. G. Lee, *J. Organometal. Chem.*, **22**, 537 (1970).

(32) This conclusion is supported by the observation that alkylthallium diacetates have been isolated both from oxythallation[9] and from organometallic exchange reactions.[33,34]

(33) H. Kurosawa and R. Okawara, *Inorg. Nucl. Chem. Lett.*, **3**, 93 (1967).

(34) H. Kurosawa and R. Okawara, *J. Organometal. Chem.*, **10**, 211 (1967).

(35) A. McKillop, J. S. Fowler, M. J. Zelesko, J. D. Hunt, E. C. Taylor, and G. McGillivray, *Tetrahedron Lett.*, 2423 (1969).

(36) A. McKillop, J. S. Fowler, M. J. Zelesko, J. D. Hunt, E. C. Taylor, G. McGillivray, and F. Kienzle, *J. Amer. Chem. Soc.*, **93**, 4841 (1971).

(37) E. C. Taylor, F. Kienzle, R. L. Robey, A. McKillop, and J. D. Hunt, *ibid.*, **93**, 4845 (1971).

(38) The difference between TTFA and thallium(III) acetate as electrophiles is also illustrated by the fact that, in contrast to TTFA, thallium(III) acetate will not effectively thallate aromatic compounds: A. McKillop, D. Bromley, and E. C. Taylor, *J. Org. Chem.*, **37**, 88 (1972).

(39) Yields of rearrangement products could be significantly improved by employing ether rather than TFA as solvent; under these conditions thallium(III) acetate failed to react.

(40) A. A. Noyes and C. S. Garner, *J. Amer. Chem. Soc.*, **58**, 1268 (1936).

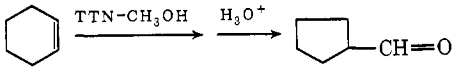
Table II. Oxidative Rearrangement of Olefins by TTN-CH_3OH

Compd no.	Olefin	Product	Yield, %[a]
6	Cyclohexene	Cyclopentanecarboxaldehyde	85[b]
7	3-Methylcyclohexene	2-Methylcyclopentane-carboxaldehyde	64[b]
8	Cycloheptene	Cyclohexanecarboxaldehyde	86[b]
9	Cyclooctene	Cycloheptanecarboxaldehyde	21[b]
10	1-Decene	1,2-Dimethoxydecane + 2-decanone	52 28
11	Styrene[c]	Phenylacetaldehyde	85
12	*p*-Bromostyrene	1-*p*-Bromophenyl-1,2-dimethoxyethane + *p*-bromophenylacetaldehyde	57 30
13	*p*-Methoxystyrene	1-*p*-Methoxyphenyl-1,2-dimethoxyethane + *p*-methoxyphenylacetaldehyde	30 64
14	α-Methylstyrene	Phenylacetone	81
15	1,1-Diphenylethylene	Deoxybenzoin	95
16	1-*p*-Bromophenyl-1-phenylethylene	4-Bromodeoxybenzoin	92
17	1-*p*-Methoxyphenyl-1-phenylethylene	4′-Methoxydeoxybenzoin	83
18	1-*p*-Bromophenyl-1-*p*-methoxyphenylethylene	4-Bromo-4′-methoxydeoxybenzoin[d]	98
19	1,1-Di-*p*-methoxyphenylethylene	4,4′-Dimethoxydeoxybenzoin	95
20	α-Methylstilbene	1,1-Diphenylacetone	66[e]
21	Dihydropyran	Tetrahydrofurfural	65

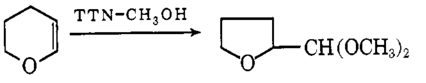
[a] Based on pure recrystallized or redistilled material. [b] Isolated as the 2,4-dinitrophenylhydrazone derivative. [c] Reaction carried out in 2% nitric acid solution. [d] Colorless needles from ethanol, mp 114–115°. *Anal.* Calcd for $C_{15}H_{13}BrO_2$: C, 59.82; H, 4.21; Br, 25.68. Found: C, 59.72; H, 4.23; Br, 25.54. [e] Based on starting material consumed.

by dissolving thallium(III) oxide in hot concentrated nitric acid and cooling the resulting solution. It is a stable, colorless, crystalline solid which is soluble in alcohols, glyme, and dilute mineral acids. By contrast, its reduction product, thallium(I) nitrate, is insoluble or only moderately soluble in all common solvents, and hence reactions can be monitored visually. Moreover, nitrate ion is even less nucleophilic than trifluoroacetate ion, and hence solvent may participate selectively as the nucleophile in oxythallation reactions with TTN.

Oxidative rearrangement of simple olefins with TTN in methanol (to give dimethylacetals or -ketals) or in dilute mineral acid (to give carbonyl compounds directly) occurred almost instantaneously at room temperature. With cyclohexene, for example, precipitation of thallium(I) nitrate was complete within 1 min, and cyclopentanecarboxaldehyde (isolated as its 2,4-DNP) was formed in 85% yield (eq 1).[41] An analogous ring contraction occurred with dihydropyran to give tetrahydrofurfural dimethyl acetal (65%) (eq 2). Oxidation of a variety of olefins was carried out similarly, and yield data for representative conversions are listed in Table II.[42] From these data, and the results described below, it proved possible to assess the scope and limitations of this reaction.

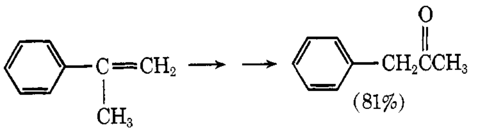


(1)

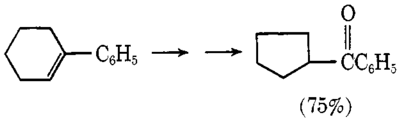


(2)

Oxidation occurred most rapidly with disubstituted olefins and was complete within a few minutes (*e.g.*, eq 3). Trisubstituted olefins reacted much more slowly (*e.g.*, eq 4). There was effectively no reaction with tetrasubstituted olefins such as 1,1-diphenyl-2,2-dimethylethylene, whereas tetraalkyl olefins generally gave mixtures of products. Bicyclohexylidene, on the other hand, smoothly gave bi-1-cyclohexen-1-yl, and we suggest that this product arises as depicted below (eq 5); the two successive deprotonation steps apparently take precedence over normal solvolysis because of the crowded environment of the organothal-



(3)



(4)

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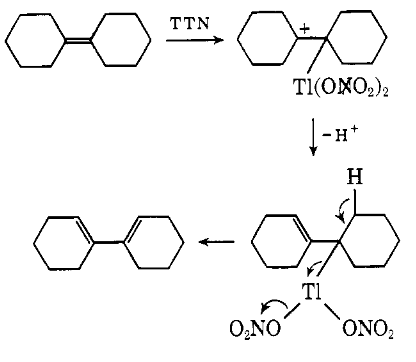
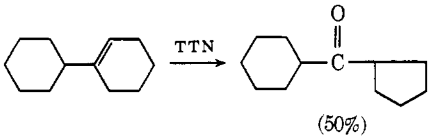
(41) This reaction without question represents the method of choice for the preparation of cyclopentanecarboxaldehyde. For a recent synthesis (58.5% yield in two steps) from cyclopentanone and references to alternate procedures, see M. de Botton, *C. R. Acad. Sci., Ser. C*, **272**, 118 (1971).

(42) We have noted that the normal TTN oxidations in methanol leading to oxidative rearrangement are at times accompanied by a minor side reaction which gives varying amounts (5–15%) of glycol mononitrate esters. A careful examination of the TTN-CH_3OH oxidation of cyclohexene to cyclopentanecarboxaldehyde showed that the mononitrate ester formed in this case was not an intermediate in the ring contraction reaction. Also, we have been informed (Professor A. R. Pinder, private communication) that attempts to effect this ring contraction under the above conditions with some cyclohexenes gave varying amounts of the vinyl methyl ether. In our hands no detectable amount of vinyl ether was observed with any of the simple olefins described herein.



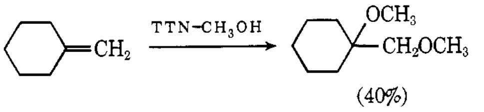
(5)

lium intermediate. A reasonable alternative mechanism involving thallation of the isomeric 1-cyclohexylcyclohexene (which might be presumed to be present as an impurity, or in equilibrium with bicyclohexylidene) was readily eliminated by the observation that treatment of authentic 1-cyclohexylcyclohexene under the reaction conditions led to cyclopentyl cyclohexyl ketone (eq 6).

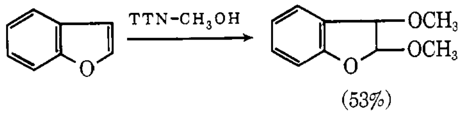


(6)

Oxidative rearrangement was the exclusive or predominant reaction pathway observed with simple six- and seven-membered cyclic olefins;[43] in these compounds the ring bond (C_2–C_3) in the oxythallation adduct is almost certainly conformationally trans to the departing thallium substituent, and hence ring contraction is the preferred reaction pathway (see Table II). With simple aliphatic olefins and cyclic olefins in which a similar, conformationally favorable pathway is not possible, yields of rearranged products were rather low, and 1,2-dimethoxy derivatives were the major products (eq 7 and 8).

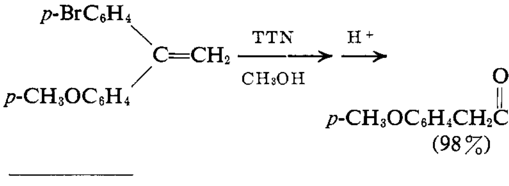


(7)



(8)

Appreciable quantities of 1,2-dimethoxyethanes were also formed on treatment of styrenes with TTN in methanol. When oxidation was carried out in very dilute nitric acid, however, arylacetaldehydes were obtained in good yields. With substrates in which more than one substituent group could theoretically migrate, rearrangement occurred cleanly to give the product expected on the basis of their relative migratory aptitudes (*e.g.*, eq 9).

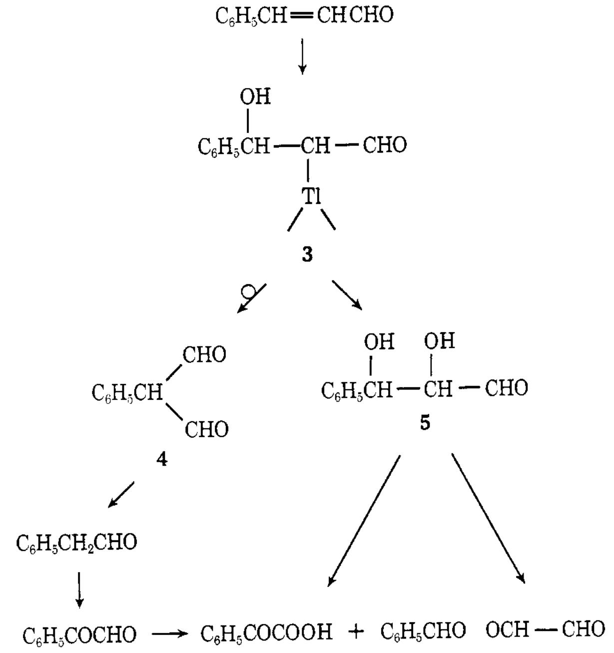


$$(p\text{-BrC}_6\text{H}_4)(p\text{-CH}_3\text{OC}_6\text{H}_4)\text{C=CH}_2 \xrightarrow[\text{CH}_3\text{OH}]{\text{TTN}} \xrightarrow{\text{H}^+} p\text{-CH}_3\text{OC}_6\text{H}_4\text{CH}_2\overset{\text{O}}{\overset{\|}{\text{C}}}\text{C}_6\text{H}_4\text{Br-}p \quad (9)$$

(98%)

Complex mixtures of products were obtained from olefins which contained other functional groups such as OH and NH_2 which are easily oxidized by TTN. α,β-Unsaturated aldehydes, esters, nitriles, and conjugated dienes reacted slowly with TTN, and in general gave complex mixtures of products.[44] For example, seven products were obtained on oxidation of cinnamaldehyde in dilute nitric acid, four of which were identified as phenylacetaldehyde, phenylglyoxal, phenylglyoxylic acid, and benzaldehyde. Formation of these products can readily be rationalized as shown in Scheme II. Direct SN2 type solvolysis of **3** to give **5** takes place to an appreciable extent, presumably because oxidative rearrangement, unless it occurs in a synchronous fashion, necessitates formation of a carbonium ion intermediate α to an already electropositive carbon. Acid catalyzed Claisen cleavage of the initial product (**4**) of oxidative rearrangement leads to phenylacetaldehyde, and control experiments established that oxidation of this latter compound with TTN gives benzaldehyde and phenylglyoxylic acid *via* the intermediacy of phenylglyoxal. Benzaldehyde is also formed by cleavage of the glycol **5**.

Scheme II



Within the limitations described above, the TTN-induced oxidative rearrangement of olefins constitutes a simple and rapid procedure for the synthesis of aldehydes and ketones, and is, we believe, the method of choice for the preparation of most of the products listed in Table II. Furthermore, the present results confirm the importance of the nature of the metal salt used in oxythallation reactions, and show that at least partial control of the reaction pathway may be achieved by appropriate choice of oxidant and reaction conditions. It is also apparent that TTN should not be a unique reagent for oxidative rearrangement; other highly ionic salts such as the sulfate and the perchlorate should function equally well. Halpern and his coworkers have recently provided confirmation of

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[43] See also E. J. Corey and T. Ravindranathan, *Tetrahedron Lett.*, 4753 (1971).

[44] See, however, A. McKillop, B. P. Swann, and E. C. Taylor, *Tetrahedron Lett.*, 5281 (1970), for the reactions of chalcones with TTN.

this postulate; oxidation of 1-methylcyclobutene with an aqueous solution of thallium(III) perchlorate resulted in almost quantitative ring contraction to give cyclopropyl methyl ketone.[45,46] From an experimental point of view, however, the perchlorate is less attractive than the nitrate, as it can only be used in aqueous solution; the crystalline salt is extremely difficult to prepare.

Comparison of thallium(III) and mercury(II) reveals that (i) Tl(III) → Ti(I) is the more powerful oxidizing system;[40] (ii) under comparable reaction conditions, Tl(III) is the more selective electrophile; and (iii) carbon–metal bond heterolysis takes place more rapidly with thallium due to the greater electron affinity of thallium(III) relative to mercury(II).[30] As demonstrated by the above results, therefore, it is possible to extend the synthetic utility of oxythallation reactions by an appropriate choice of reagent and reaction conditions.

Experimental Section[47]

Starting Materials. Compounds **6–14**, **20**, and **21** were commercially available and were purified prior to use. The following compounds were prepared by literature procedures: **15**,[48] **16**,[49] **17**,[50] **19**.[51]

1-*p*-Bromophenyl-1-*p*-methoxyphenylethylene (18). *p*-Bromoacetophenone (40 g, 0.22 mol) was added dropwise during 2 hr to a stirred solution of *p*-methoxyphenylmagnesium bromide in ether (from 41 g (0.22 mol) of *p*-bromoanisole and 5.2 g (0.22 mol) of magnesium in 200 ml of ether). Sulfuric acid (100 ml, 30% aqueous) was then added and the mixture heated under reflux for 1 hr. The organic layer was separated, the aqueous layer was extracted with ether, and the combined extracts were dried (Na_2SO_4). Evaporation of the solvent and crystallization of the residue from 2-propanol gave 38 g (60%) of pure product as fine colorless needles, mp 94–95°.

Anal. Calcd for $C_{15}H_{13}BrO$: C, 62.30; H, 4.54; Br, 27.64. Found: C, 62.07; H, 4.84; Br, 27.57.

Thallium(III) Nitrate. Thallium(III) oxide (45 g) was stirred in hot (*ca.* 50°) concentrated nitric acid (120 ml). After about 0.5 hr all of the oxide had dissolved and the resulting clear colorless solution was cooled to 0°. The colorless solid which crystallized was removed by filtration, washed with a little cold, dilute nitric acid, and dried in a vacuum dessicator over phosphorus pentoxide. This gave 75 g (85%) of TTN·$3H_2O$ as hard, colorless crystals which were stored in the cold in a tightly sealed bottle.

General Procedure for the Oxidation of Cyclic Olefins with TTFA–Ether. Thallium(III) trifluoroacetate (5.43 g. 0.01 mol)[6] was dissolved in a mixture of anhydrous ether (200 ml), trifluoroacetic acid (5 ml), and trifluoroacetic anhydride (0.5 ml). The olefin (0.01 mol) was added to the colorless solution, and the reaction was stirred at room temperature until thallium(I) trifluoroacetate had separated as a fine, colorless precipitate.

Reaction soon appeared to be complete (*e.g.*, approximately 10 min for cyclohexene), but yields of ring-contracted products were slightly higher when the reaction mixtures were allowed to stand for longer periods of time (cyclohexene, 1 day; cycloheptene, 2 days; cyclooctene, 4 days). To this suspension was then added an alcoholic solution containing 0.01 mol of 2,4-dinitrophenylf hydrazine[52] and the mixture was evaporated to one-third o- its volume. Ethanol (50 ml) and water (50 ml) were added and the mixture was heated on a steam bath for 30 min. Cooling resulted in crystallization of the crude 2,4-dinitrophenylhydrazone of the ring-contracted aldehyde, which was collected by filtration and crystallized from benzene–methanol.

In parallel experiments the addition of 2,4-dinitrophenylhydrazine was omitted. The ether suspension was extracted twice with 25 ml of water and once with 25 ml of a 5% sodium bicarbonate solution. Evaporation of the dried ether layer (anhydrous sodium sulfate) gave the crude reaction product whose composition was investigated by gas chromatography. Compounds were identified either by comparison of retention times with authentic samples or by preparative vpc followed by examination of physical and spectral data.

Oxidation of 5α-Cholest-2-ene. The oxidation of 5α-cholest-2-ene (1.48 g, 0.004 mol) with TTFA in 200 ml of ether, 4 ml of TFA, and 0.5 ml of trifluoroacetic anhydride was carried out as described above. After 4 days at room temperature the reaction mixture was evaporated to dryness; the residue was heated on a steam bath with 40 ml of 10% sulfuric acid for 1 hour and then extracted once with 200 ml of ether. Evaporation of the ether solution left a partly solid residue which was dissolved in 50 ml of acetone and oxidized with 40 drops of Jones' solution.[53] After 1 hr at room temperature the mixture was filtered and the filtrate evaporated. Water (100 ml) was added and the resulting mixture extracted twice with 100-ml portions of ether. The combined ether extracts were then extracted three times with 25-ml portions of 5% potassium hydroxide solution. The combined alkaline solutions were acidified with 10% sulfuric acid and then extracted with ether. Evaporation of the ether extracts gave crude 2β-carboxy-*A*-norcholestene (242 mg, mp 170–174°) which was isolated by filtration following trituration in cold water. Upon recrystallization from acetone the acid melted at 188–190°, $[\alpha]_D$ +14° (*c* 0.2, $CHCl_3$).[54] Its infrared spectrum showed broad absorption at 3500–2500 cm^{-1}, a strong carbonyl band at 1700 cm^{-1}, and weaker absorptions at 1300, 1230, 1205, 1135, 1115, 975–875 (broad), and 720 cm^{-1}.

A small sample of the *crude* acid was esterified with diazomethane. The nmr spectrum of the resulting crude methyl ester (in benzene) showed one peak for the C-19 methyl at τ 9.20. This is in agreement with the presence of *only* the β ester.[55] Cava and coworkers[54] have shown that in the α isomer the C-19 methyl resonance occurs at τ 9.35 and in the β isomer at τ 9.20.

The oxidation of 5α-cholest-2-ene with thallium(III) nitrate in methanol–ether (80:20), followed by work-up after 1 day as described above for the TTFA reaction, gave analogous results (9% yield).

General Procedure for the Oxidation of Olefins with TTN–Methanol. Thallium(III) nitrate trihydrate (4.4 g, 0.01 mol) was dissolved in 50 ml of methanol and the olefin (0.01 mol) was added. The reaction mixture was stirred at room temperature or

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[45] J. E. Byrd, L. Cassar, P. E. Eaton, and J. Halpern, *Chem. Commun.*, 40 (1971). These oxidations were carried out in extremely dilute aqueous solutions, with the solubility of the hydrocarbon in water the limiting factor, and consequently were of only limited applicability to synthetic manipulations.

[46] Following completion of our work, we became aware of a patent [A. H. Frye, assignor to The Cincinnati Milling Machine Co., Cincinnati, Ohio; U. S. Patent 3,452,047 (1969)] describing the oxidation of a number of olefins, including cyclohexene and some styrenes, with aqueous acidic solutions of various thallium(III) salts to give products similar to those described in this paper.

[47] Melting points were determined using a Kofler hot-stage microscope melting point apparatus and are uncorrected. Microanalyses were performed by Mr. A. R. Saunders of the University of East Anglia and by Dr. G. Robertson, Florham Park, N. J. Where appropriate, identity of products was confirmed by comparison of ir spectra, determined on Perkin-Elmer Models 237B and 257 grating infrared spectrophotometers using the normal Nujol mull or liquid film techniques, and nmr spectra, determined as solutions in carbon tetrachloride or deuteriochloroform using TMS as internal standard, on Perkin-Elmer R12 60 MHz and Varian A60-A instruments. Glpc traces were obtained from Perkin-Elmer Models 452 and F11 flame ionization gas chromatographs equipped with a 2-m Apiezon column and a 50-m PPG capillary column, respectively, and with an Aerograph Model A90-P3 instrument utilizing an 18 ft × $^3/_8$ in. column packed with 20% SE-30 or 30% QF-1 on 45–60 Chromosorb W, unless otherwise specified.

[48] C. F. H. Allen and S. Converse, "Organic Syntheses," Collect. Vol. I, 2nd ed, Wiley, New York, N. Y., 1944, p 226.

[49] S. N. Ege and K. W. Shenk, *J. Amer. Chem. Soc.*, **75**, 354 (1953).

[50] C. D. Hurd and C. N. Webb, *ibid.*, **49**, 546 (1927).

[51] P. Pfeiffer and R. Wizinger, *Justus Liebigs Ann. Chem.*, **461**, 132 (1928).

[52] This was prepared as described in R. L. Shriner, R. C. Fuson, and D. Y. Curtin, "The Systematic Identification of Organic Compounds," 5th ed, Wiley, New York, N. Y., 1964, p 253.

[53] K. Bowden, I. M. Heilbron, E. R. H. Jones, and B. C. Weedon, *J. Chem. Soc.*, 39 (1946).

[54] Mp 186–188° (table), 195–196° (experimental), $[\alpha]_D$ +13°: M. P. Cava, P. M. Weintraub, and E. J. Glamkowski, *J. Org. Chem.*, **31**, 2015 (1966).

[55] The absence of any detectable α isomer is not a reliable indication of the mode of attack of TTFA on the double bond, since it has been reported [M. Mousseron, R. Jacquier, and H. Christol, *C. R. Acad. Sci.*, **236**, 927 (1953)] that 3-substituted cyclopentanecarboxaldehydes isomerize even under mild conditions.

heated until a starch–iodide test indicated complete reduction of Tl(III) to Tl(I) (with cyclic olefins and styrenes, reaction was complete within a few minutes). The reaction mixture was then filtered, and an alcoholic solution containing 0.01 mol of 2,4-dinitrophenylhydrazine was added to the filtrate. The resulting mixture was evaporated to $^1/_3$ of its volume and, after addition of 10 ml of water, heated on a steam bath for 10 min. After cooling to 0°, the 2,4-dinitrophenylhydrazone of the carbonyl compound was collected by filtration.

On a preparative scale, the reaction mixture was filtered from precipitated thallium(I) nitrate, the filtrate evaporated to a small volume, and the resulting mixture of the carbonyl compound and its acetal (or ketal) heated on a steam bath for 30 min with an excess of 5% sulfuric acid. The free carbonyl compound was isolated by ether extraction followed by final distillation or crystallization.

2,3-Dimethoxy-2,3-dihydrobenzofuran. To a stirred solution of 2.36 g (20 mmol) of freshly distilled benzofuran[56] in 25 ml of methanol at room temperature was added a solution of 8.88 g (20 mmol) of TTN in 25 ml of anhydrous methanol. The solution instantly turned yellow and a colorless precipitate separated. The mixture was gently refluxed for 6 hr until starch–iodide paper no longer showed the presence of thallium(III). Sodium chloride (1.2 g, 20.7 mmol) and decolorizing charcoal were added and the mixture was stirred for 1 hr and then filtered. Evaporation of the methanol filtrate gave 3.55 g of a light yellow liquid which was distilled at 110° (7 mm) to give 1.91 g (53%) of 2,3-dimethoxy-2,3-dihydrobenzofuran as a pale yellow oil: nmr ($CDCl_3$) δ 6.7–7.5 (br s, 4), 5.4 (d, J = 1.2 Hz, 1), 4.67 (br s, 1), 3.4 (s, 3, OCH_3), 3.34 (s, 3, OCH_3); ir 3060, 3000, 2940, 2830, 1615, 1600, 1480, 1470, 1370, 1325, 1235, 1190, 1100, 1000, 940, 920, 880, 820, and 750 cm^{-1}.

Anal. Calcd for $C_{10}H_{12}O_3$: C, 66.65; H, 6.71. Found: C, 66.33; H, 6.66.

Oxidation of Bicyclohexylidene to Bi-1-cyclohexen-1-yl. To a solution of 8.2 g (50 mmol) of bicyclohexylidene[57] in a mixture of 100 ml of methanol and 10 ml of diethyl ether was added 25.5 g (57.5 mmol) of thallium(III) nitrate. A colorless precipitate separated immediately. The mixture was stirred at room temperature for 14 hr, and the formation of product was followed by tlc using silica gel plates and hexane solvent. To the reaction mixture was added 3 g of sodium chloride, and the inorganic salts were removed by filtration. After evaporation to about 30 ml, 100 ml of chloroform was added. This solution was washed once with 50 ml of saturated sodium chloride solution and twice with 50 ml of distilled water. The resulting organic layer was separated, dried over calcium chloride, filtered, and distilled under reduced pressure. The fraction (5.32 g, 65%) boiling at 93–98°(5–8 mm) was collected. The nmr[58] and uv[59] data taken on material purified by preparative glc were in agreement with published values.

In a similar experiment, the crude diene was reacted with tetracyanoethylene (TCNE) in benzene and worked up as described by Drake to give the TCNE Diels–Alder adduct, mp 139° (lit.[60] mp 141°).

Cyclohexyl Cyclopentyl Ketone. To a solution of 1.64 g (10 mmol) of 1-cyclohexyl-1-cyclohexene[61] in 30 ml of methanol and 3 ml of diethyl ether was added 4.8 g (11 mmol) of thallium(III) nitrate (TTN). A precipitate formed immediately. The reaction mixture was stirred 2.5 hr at room temperature and 2.5 hr at reflux, and then diluted with 20 ml of distilled water, filtered, and evaporated to 25 ml under vacuum. An additional 30 ml of water was added and the resulting solution extracted twice with 30-ml portions of chloroform. The combined extracts were washed with two 30-ml portions of distilled water, dried over magnesium sulfate, filtered, and evaporated to give 2.1 g. Glc on a 30% QF-1 column indicated two major products, several minor products, and starting material. The two products were isolated by preparative glc and shown to be 1-cyclohexyl-6-methoxycyclohexene [nmr ($CDCl_3$) δ 5.4 (br, 1), 3.7 (br, 1), 3.35 (s, 3, OCH_3), 1 to 2.2 (br, 21); ir 3050 (w), 2920, 1450, 1185, 1090, 940, 915 cm^{-1}] and cyclohexyl cyclopentyl ketone [ir 1710 cm^{-1}; 2,4-dinitrophenylhydrazone, mp 133–134° (lit.[62] 135–136°); oxime, mp 113–115°. *Anal.* Calcd for $C_{12}H_{21}NO$ (oxime): C, 73.79; H, 10.84; N, 7.17. Found: C, 73.97; H, 10.52; N, 7.20] in a ratio of 1:2.35.

Cyclopentyl Phenyl Ketone. To a solution of 1.58 g (0.01 mol) of 1-phenylcyclohexene in 25 ml of methanol was added 4.44 g (0.01 mol) of thallium(III) nitrate (TTN). A white precipitate formed immediately. The reaction mixture was stirred at room temperature for 12 hr, and then 1.7 g of sodium chloride was added. The colorless solution was stirred several minutes, filtered, and evaporated under reduced pressure to give an amber residue. This residue was taken up in 30 ml of chloroform, washed once with 20 ml of saturated sodium chloride solution followed by 20 ml of distilled water, dried over magnesium sulfate, filtered, and vacuum evaporated to give 1.9 g of an amber liquid. Glc (20% SE-30) shows one major product (75% for a yield of 80% based on the weight of crude product). The major compound was isolated by preparative glc (ir, 1675 cm^{-1}), 2,4-dinitrophenylhydrazone mp 141–143° (lit.[63] mp 144°).

Tetrahydrofurfural Dimethyl Acetal. To a solution of 1.88 g (22.4 mmol) of distilled dihydropyran (**21**) in 35 ml of anhydrous methanol was added 4.4 g (10 mmol) of thallium(III) nitrate (TTN); the resulting mixture was stirred at *ca.* 60° for 12 hr. Sodium chloride (0.6 g) was added, and the reaction mixture was stirred 1 hr and then filtered to remove precipitated inorganic salts. The filtrate was evaporated to one-third of its volume, dissolved in 50 ml of methylene chloride, and washed twice with 25-ml portions of saturated sodium chloride solution and once with distilled water. The extract was dried over magnesium sulfate, filtered, and distilled under reduced pressure. The yield of tetrahydrofurfural dimethyl acetal, bp 44–46° (6 mm), was 0.96 g (65% based on TTN added): nmr ($DCCl_3$) δ 4.23 (d, J = 6 Hz, 1), 3.70–4.00 (m, 3), 3.4 (s, 6, OCH_3), 1.8–2.1 (m, 4); ir 2950, 2830, 1470, 1450, 1180, 1075, 970, and 920 cm^{-1}; mass spectrum m/e 146 (P), 75 (base), 45 (47), 71 (18), 115 (14), and 31 (29).

Anal. Calcd for $C_7H_{14}O_3$: C, 57.51; H, 9.65. Found: C, 57.55; H, 9.56.

1-Methoxy-1-methoxymethylcyclohexane. To a solution of 0.96 g (0.01 mol) of methylenecyclohexane[64] in 25 ml of methanol at −30° was added 4.4 g (0.01 mol) of thallium(III) nitrate (TTN). A precipitate formed immediately. The reaction mixture was stirred 2 hr at −10 to −30° and then 2 hr at room temperature. Sodium chloride (0.6 g) was added, and the reaction mixture was stirred 15 min, filtered, and evaporated to about 5 ml. The residue was diluted to 40 ml with saturated sodium chloride solution and extracted twice with 40 ml of methylene chloride. The combined extracts were dried over anhydrous magnesium sulfate, filtered, and evaporated under reduced pressure to give 1.21 g of crude product. Glc on 20% SE-30 indicated two major products in a ratio of 1:1.8. The greater product was assigned the structure 1-methoxy-1-methoxymethylcyclohexane (*Anal.* Calcd for $C_9H_{18}O_2$: C, 68.31; H, 11.47. Found: C, 68.31; H, 11.38. Nmr ($DCCl_3$): δ 3.30 (s, 3, OCH_3), 3.20 (s, 2, OCH_2), 3.17 (s, 3, OCH_3), *ca.* 1.4 (br, 10); ir strong bands at 1450, 1100, and 1075 cm^{-1}). The lesser product has been tentatively assigned the structure 1-methoxymethylcyclohexene [nmr: δ 5.72 (m, 1), 3.78 (br s, 2), 3.27 (s, 3, OCH_3), br m centered at 2.0 and 1.65, 8; ir 3050, 1675, 1100, 1080, 820, and 790 cm^{-1}]. Reaction of the crude product with boron trifluoride etherate for 2 hr at room temperature caused a disappearance of the major product and the appearance of a new peak not present in the original product. Therefore the allyl ether is probably a primary reaction product and does not result from acid-catalyzed elimination of methanol from the dimethoxy compound.

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