Reactions of Silver Perchlorate and of Silver Triflate with Alkyl Iodides. Solvent Inhibition of Isomerization[1]

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Primary alkyl iodides reacted with silver perchlorate and with silver triflate in pentane, carbon tetrachloride, or 1,1,2-trichlorotrifluoroethane to give mixtures of the primary and secondary perchlorates and triflates, respectively, with secondary isomers predominating. In benzene, only the unrearranged products were obtained. An excess of alkyl iodide and, to a lesser extent, methylene chloride also inhibited isomerization. Isopropyl iodide and allyl iodide, as well as primary iodides, were converted to the corresponding perchlorates and triflates in high yield. Inhibition of rearrangement is rationalized on the basis of lessened reactivity of complexed silver ions.

Substitution reactions of alkyl halides with silver salts are widely used synthetic methods. With poorly nucleophilic anions, however, the utility has been limited because of isomerization. The reaction of silver perchlorate with primary alkyl iodides in pentane gave mainly secondary perchlorates,[2] and the reaction of silver trifluoromethanesulfonate with propyl iodide under the same conditions also was reported to give mainly isopropyl triflate.[3] No evidence of rearrangement was reported in reactions of alkyl halides with silver salts of more nucleophilic anions, such as nitrite,[4] nitrate,[5] and toluenesulfonate.[6] The present paper deals with the effects of solvents on the reactions of silver perchlorate and silver triflate with alkyl iodides and describes selective synthetic procedures for simple primary perchlorates and triflates.

The initial studies were carried out using propyl iodide, since only one secondary substitution product is possible, and the isomeric perchlorates[2] and triflates[3,7] are readily distinguished by nmr. Propyl iodide reacted with a suspension of anhydrous silver perchlorate in pentane, carbon tetrachloride, or 1,1,2-trichlorotrifluoroethane to give a quantitative yield of perchlorates, consisting of 60% isopropyl perchlorate and 40% propyl perchlorate. The product ratio in this heterogeneous reaction was affected by variables such as the particle size of the silver perchlorate and the rate of stirring. variations of up to 10% in yields of the components were observed, but the total yield remained essentially quantitative.

When this reaction was carried out in benzene, in which silver perchlorate is soluble, a 91% yield of propyl perchlorate was obtained. No isopropyl perchlorate was detected by nmr or by glpc of the displacement products with lithium bromide, and no benzene alkylation products were detected. When such a large excess of silver perchlorate was used that the salt was mainly out of solution, the same results were obtained, showing that the results were not due simply to homogeneous and heterogeneous reactions. The use of mixtures of carbon tetrachloride and benzene gave intermediate results. Thus, a solvent consisting of 33% benzene and 67% carbon tetrachloride gave an equal mixture of propyl perchlorate and isopropyl perchlorate. A solvent consisting of 67% benzene and 33% carbon tetrachloride gave a product containing 15% isopropyl perchlorate and 85% propyl perchlorate. Methylene chloride as a reaction solvent also gave results intermediate between those for benzene and carbon tetrachloride and the product consisted of 62% propyl perchlorate and 38% isopropyl perchlorate. The use of an excess of propyl iodide, with carbon tetrachloride as the reaction solvent, was also found to reduce the amount of rearrangement. Twice the theoretical amount of propyl iodide gave 41% rearranged product, and four times the theoretical amount of propyl iodide gave only 23% rearrangement.

Reactions of silver triflate with propyl iodide gave results similar to those of silver perchlorate. In carbon tetrachloride, pentane, or 1,1,2-trichlorotrifluoroethane, the product consisted of 34% propyl triflate and 66% isopropyl triflate. Methylene chloride gave 59% propyl triflate and 41% isopropyl triflate. Benzene gave completely unrearranged propyl triflate. Also, as in the perchlorate reactions, diluted benzene gave intermediate results. Thus, 33% benzene in 1,1,2-trichlorotrifluoroethane gave 57% rearrangement, 50% benzene gave 49% rearrangement, and 67% benzene gave 23% rearrangement. An excess of propyl iodide as solvent gave only unrearranged propyl triflate.

For preparative purposes, carbon tetrachloride and similar solvents are preferred for substrates that do not isomerize readily. The reactions are more rapid than those in benzene solution, and the products are observed conveniently by nmr. Benzene is the solvent of choice for substrates prone to rearrangement. Preparations of organic perchlorates and triflates from silver perchlorate and silver triflate are shown in Tables I and II, respectively. Spectral properties of the perchlorates were identical with those of the compounds obtained from the corresponding alcohols and dichlorine heptoxide.[2] Triflates were compared likewise with authentic samples.[7] Pentyl triflate, hexyl triflate, and decyl triflate were isolated, and the latter two, which are new compounds, were analyzed. Propyl triflate was also prepared independently from propanol and triflic anhydride.

Hexyl iodide and silver perchlorate in carbon tetrachlo-

Table I
Reactions of Alkyl Iodides with Silver Perchlorate

Starting material	Registry no.	Product	Solvent	Yield, %
CH_3I	74-88-4	CH_3OClO_3	CCl_4	81
CH_3CH_2I	75-03-6	$CH_3CH_2OClO_3$	CCl_4	99
$(CH_3)_2CHI$	75-30-9	$(CH_3)_2CHOClO_3$	CCl_4	98
$CH_2{=}CHCH_2I$	556-56-9	$CH_2{=}CHCH_2OClO_3$	CCl_4	96
$CH_3CH_2CH_2I$	107-08-4	$CH_3CH_2CH_2OClO_3$	C_6H_6	91
$CH_3(CH_2)_3CH_2I$	628-17-1	$CH_3(CH_2)_3CH_2OClO_3$	C_6H_6	86
$CH_3(CH_2)_4CH_2I$	638-45-9	$CH_3(CH_2)_4CH_2OClO_3$	C_6H_6	87

Table II
Reactions of Alkyl Iodides with Silver Triflate

Starting material	Product	Solvent	Yield, %
CH_3I	$CH_3OSO_2CF_3$	CCl_4	85
CH_3CH_2I	$CH_3CH_2OSO_2CF_3$	CCl_4	98
$(CH_3)_2CHI$	$(CH_3)_2CHOSO_2CF_3$	CCl_4	97
$CH_2{=}CHCH_2I$	$CH_2{=}CH_2CHOSO_2CF_3$	CCl_4	95
$CH_3CH_2CH_2I$	$CH_3CH_2CH_2OSO_2CF_3$	C_6H_6	92
$CH_3(CH_2)_3CH_2I$	$CH_3(CH_2)_3CH_2OSO_2CF_3$	C_6H_6	82
$CH_3(CH_2)_4CH_2I$	$CH_3(CH_2)_4CH_2OSO_2CF_3$	C_6H_6	91
$CH_3(CH_2)_8CH_2I$	$CH_3(CH_2)_8CH_2OSO_2CF_3$	C_6H_6	93

ride gave mainly secondary perchlorates, and both 2-hexyl perchlorate and 3-hexyl perchlorate were identified as the corresponding bromides following reaction with lithium bromide.

$$CH_3(CH_2)_5I + AgClO_4 \xrightarrow{CCl_4} CH_3(CH_2)_5OClO_3 + CH_3(CH_2)_3CH(OClO_3)CH_3 + CH_3(CH_2)_2CH(OClO_3)CH_2CH_3$$

Both alkyl perchlorates and alkyl triflates have been utilized as alkylating agents without separating them from the nonpolar solvents in which they were prepared.[2,7] Triflates are preferable for general synthetic use because of their somewhat greater reactivity and because they can be handled safely as neat materials. The reactions of commercially available silver perchlorate and silver triflate with alkyl iodides in appropriate solvents provide convenient and selective preparative routes to these potent alkylating agents. The methods would be expected to be applicable to other weakly nucleophilic anions. The silver salt reactions complement the reactions of alcohols with dichlorine heptoxide[2] and with triflic anhydride[7] as practical routes to perchlorates and triflates. Thus, the anhydride methods are superior for substrates with electron-withdrawing substituents since the halides are unreactive, whereas the silver reactions can be applied to reactive halogens where the corresponding alcohols are unstable.

Silver salt displacement reactions have been rationalized on the basis of ion-pair mechanisms with both silver ion and the displacing nucleophile participating in the transition state[8,9] or on the basis of a concerted push–pull mechanism.[10] The degree of participation by silver is envisioned as a function of the nucleophilic power of the anion, with poor nucleophiles requiring a greater degree of carbon–halogen bond breaking in the transition state. Perchlorate and triflate which are the least nucleophilic anions that have been used in silver salt displacements should require a relatively high degree of carbonium ion character in the transition state. These systems should therefore be more prone to isomerization than in the case of more nucleophilic anions.

The lack of isomerization in benzene can be rationalized on the basis of complexation of silver ions by the solvent. It is noteworthy that the reaction is significantly slower in benzene than in solvents such as carbon tetrachloride. It has been recognized that silver salt reaction rates are an inverse function of the complexing ability of the solvent.[9] The less active complexed silver ions would exert less "pull" on the leaving halogen, and the resulting transition state is more SN2 like. Since complexation is an equilibrium phenomenon, intermediate results in mixed solvents are to be expected. Where an excess of salt over the solubility is used, surface sites are subject to the same equilibrium deactivation. A factor contributing to the benzene effect may be increased reactivity of the anion in solution.

Kornblum and Hardies[10] observed retention of configuration in the reaction of silver nitrite or silver nitrate with α-phenethyl chloride in benzene but inversion in saturated hydrocarbons. The results were explained on the basis of a carbonium ion–benzene π complex which undergoes displacement by the anion. Inversion predominated for 2-octyl halides with these reactions as well as with the reaction of silver perchlorate in benzene.[9] The π complex mechanism thus appears applicable only to the more stable carbonium ions.

Experimental Section

Caution: Neat alkyl perchlorates are sensitive explosives and should be handled only with adequate protective devices. Dilute solutions are useable as reagents with previously noted precautions.[2]

General. Nmr spectra were recorded with a Varian T-60 spectrometer, and ir spectra were recorded with a Perkin-Elmer 700 spectrometer. Anhydrous grade silver perchlorate was dried azeotropically before use.[11] Silver triflate, prepared from triflic acid and silver oxide,[12] was dried by azeotroping with benzene until the salt was soluble; solvent was removed and the residue was dried for 5 hr at 80° (0.05 mm).

Reaction of Silver Perchlorate with Propyl Iodide. Propyl iodide (0.170 g, 1 mmol) was added with stirring to 0.207 g (1 mmol) of anhydrous silver perchlorate and 3 ml of carbon tetrachloride at 0°. After 1 hr, nmr analysis[2] of the solution, using chlorobenzene as a quantitative standard, showed a quantitative yield of a mixture of propyl perchlorate (40%) and isopropyl perchlorate (60%). Variations of up to 10% were observed in yields of the components but the total remained quantitative. Identical results were obtained using pentane or 1,1,2-trichlorotrifluoroethane as the solvent. Methylene chloride gave a 92% yield of a mixture of propyl perchlorate (62%) and isopropyl perchlorate (38%). In an experiment identical with that above using carbon tetrachloride, but with twice the theoretical amount of propyl iodide, the product consisted of 41% isopropyl perchlorate and 59% propyl perchlorate. Four times the theoretical amount of propyl iodide gave 23% isopropyl perchlorate and 77% propyl perchlorate.

The use of benzene as the reaction solvent required 18 hr of stirring at room temperature for completion. The benzene solution was filtered, washed with water, and dried over magnesium sulfate. Nmr analysis showed a 91% yield of propyl perchlorate and no trace of isopropyl perchlorate. The benzene solution was added to an equal volume of 10% lithium bromide in acetone and the mixture was washed with water and dried. Nmr and glpc showed propyl bromide but no isopropyl bromide. No rearrangement was observed when ten times the theoretical amount of silver perchlorate (2.07 g) was used, mainly out of solution.[13]

The reaction of equivalent amounts of propyl iodide and silver perchlorate for 18 hr, as above, in a solvent consisting of 33% benzene and 67% carbon tetrachloride gave a 90% yield of perchlorates consisting of 50% propyl perchlorate and 50% isopropyl perchlorate. A solvent consisting of 67% benzene and 33% carbon tetrachloride gave a 91% yield consisting of 15% isopropyl perchlorate and 85% propyl perchlorate.

Propyl perchlorate and isopropyl perchlorate were unchanged in control experiments in the presence of silver perchlorate and silver iodide.

Preparation of Alkyl Perchlorate Solutions. Equivalent amounts of silver perchlorate were reacted as above with methyl iodide, ethyl iodide, isopropyl iodide, allyl iodide, pentyl iodide, and hexyl iodide to give the corresponding perchlorates[2] with no detectable isomeric products. The respective solvents and yields are shown in Table I.

Reaction of Hexyl Iodide with Silver Perchlorate in Carbon Tetrachloride. The above procedure was used. Nmr analysis showed that the product consisted of 42% 1-hexyl perchlorate and 58% secondary perchlorates. In this mixture, 2-hexyl perchlorate and 3-hexyl perchlorate could not be resolved by nmr. The solution was added to an equal volume of 10% lithium bromide in acetone and the mixture was washed with water. A mixture of 2-bromohexane and 3-bromohexane was isolated by preparative glpc. Nmr analysis, by comparison with authentic samples, showed a 4:1 ratio of 2-bromohexane to 3-bromohexane. In control experiments, 1-hexyl perchlorate gave a quantitative yield of 1-bromohexane, and the secondary perchlorates each gave a 50% yield of the corresponding bromide.

Reaction of Silver Triflate with Propyl Iodide. Propyl iodide (0.170 g, 1 mmol) was added with stirring to 0.259 g (1 mmol) of silver triflate in 3 ml of carbon tetrachloride at ambient temperature. Yields were determined after 2 hr by both proton and fluorine nmr using benzotrifluoride as a quantitative standard. A 97% yield of triflates was obtained consisting of 34% propyl triflate and 66% isopropyl triflate. The yields of the components varied ±10% but the total was always nearly quantitative. The same results were obtained using 1,1,2-trichlorotrifluoroethane or pentane as solvent. Methylene chloride gave a 95% yield consisting of 59% propyl triflate and 41% ispropyl triflate. Using benzene as solvent (18 hr) gave a 92% yield of propyl triflate with no isopropyl triflate. A solvent consisting of 33% benzene and 67% 1,1,2-trichlorotrifluoroethane gave a 98% yield containing 43% propyl triflate and 57% isopropyl triflate; 50% benzene and 50% 1,1,2-trichlorotrifluoroethane gave a 98% yield with 51% propyl triflate and 49% isopropyl triflate; 67% benzene and 33% 1,1,2-trichlorofluoroethane gave a 94% yield with 77% propyl triflate and 23% isopropyl triflate.

Propyl Triflate. A solution of 0.30 g (5 mmol) of propanol and 0.395 g (2 mmol) of pyridine in 5 ml of carbon tetrachloride was added dropwise with stirring to a solution of 1.41 g (5 mmol) of triflic anhydride in 10 ml of carbon tetrachloride at 0°. In 15 min the solution was filtered, washed with water, and dried over magnesium sulfate. Nmr analysis using chlorobenzene as a quantitative reference, showed an 86% yield of propyl triflate: proton nmr (CCl_4) δ 4.45 (t, 2 H, J = 6 Hz, CH_2O–), 1.83 (m, 2 H, CH_2CH_2O–), and 1.08 ppm (t, 3 H, J = 6 Hz, CH_3); fluorine nmr (CCl_4) ϕ 75.80 ppm (s); ir (CCl_4) 2990 (m), 1460 (w), 1420 (vs), 1250 (s), 1220 (vs), 1155 (vs), and 950 cm^{-1} (vs).

Preparation of Alkyl Triflate Solutions. By the procedure used above for propyl iodide, equivalent amounts of silver triflate were reacted with methyl iodide, ethyl iodide, isopropyl iodide, allyl iodide, pentyl iodide, hexyl iodide, and decyl iodide to give the corresponding triflates. The respective solvents and yields are shown in Table II.

Pentyl Triflate. Pentyl iodide (0.91 g, 4.6 mmol) was added dropwise with stirring to a partial suspension of 2.40 g (9.2 mmol) of silver triflate in 25 ml of benzene. The mixture was stirred 18 hr, filtered, washed with water, dried over magnesium sulfate, and distilled to give 0.785 g (82%) of pentyl triflate, bp 55–57 (1.5 mm), with spectra identical with those reported.[7]

Hexyl Triflate. Hexyl iodide (2.12 g, 10 mmol) was reacted with 2.57 g (10 mmol) of silver triflate in 50 ml of benzene as above to give 2.13 g (91%) of hexyl triflate, bp 26–28° (0.1 mm): proton nmr (CCl_4) δ 4.43 (t, 2 H, J = 6 Hz, CH_2O), 1.80 (m, 2 H, CH_2CH_2O), 1.26 (m, 6 H, CH_2), and 0.90 ppm (m, 3 H, CH_3); fluorine nmr (CCl_4) ϕ 75.8 ppm (s); ir (CCl_4) 1420, 1225, 1155, and 940 cm^{-1} (SO_3CF_3).

Anal. Calcd for $C_7H_{13}F_3SO_3$: C, 35.90; H, 5.59. Found: C, 35.81; H, 5.72.

Decyl Triflate. Decyl iodide (4.02 g, 15 mmol) was reacted by the above procedure with 5.14 g (20 mmol) of silver triflate in 100 ml of benzene. The washed and dried benzene solution was filtered through silicic acid and stripped of solvent to give 4.05 g (93%) of decyl triflate, a colorless oil: proton nmr ($CDCl_3$) δ 4.42 (t, 2 H, J = 6 Hz, CH_2O–), 1.82 (m, 2 H, CH_2CH_2O–), 1.27 (m, 14 H, CH_2), and 0.83 ppm (m, 3 H, CH_3); fluorine nmr ϕ 75.4 (s); ir (CCl_4) 1420, 1220, 1160, and 950 cm^{-1} (SO_3CF_3).

Anal. Calcd for $C_{11}H_{21}F_3SO_3$: C, 45.50; H, 7.29; S, 11.05. Found: C, 45.44; H, 7.09; S, 11.40.

Registry No.—Silver perchlorate, 7783-93-9; silver triflate, 2923-28-6; propyl triflate, 29702-90-7; propanol, 71-23-8; triflic anhydride, 358-23-6; pentyl triflate, 41029-43-0; hexyl triflate, 53059-88-4; decyl triflate, 53059-89-5; $CH_3(CH_2)_8CH_2I$, 2050-77-3.

References and Notes

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New Carbonyl Compounds from the Alkaline Ferricyanide Dehydrogenation of *p*-Cresol

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Pummerer's ketone type trimeric ketone **8** and tetrameric ketone **9** have been obtained from the dehydrogenation of *p*-cresol with alkaline ferricyanide in addition to **1**, **2**, **3**, and **4**. The tetrameric ketone **9** is apparently formed through dehydrogenation and subsequent intramolecular radical substitution of **10** which was produced by Pummerer's ketone type oxidative coupling of the diphenyl **1**. Trimeric hemiketals **6** and **7** obtained previously from the ferric chloride dehydrogenation of *p*-cresol and/or their derivatives were not found in the alkaline ferricyanide or peroxide–peroxidase dehydrogenation of *p*-cresol. It had been concluded that in the ferric chloride dehydrogenation hemiketals **6** and **7** were formed through acid-catalyzed hydration of **12**, which was produced by dehydrogenation and subsequent intramolecular radical substitution of **10**, rather than by subsequent acid-catalyzed reactions of **11**. Dehydration of **6** by general acid catalysis results in rearrangement of the molecule involving an intramolecular ether interchange by O-5 participation of the benzofuran oxygen, followed by dienol–benzene rearrangement to give **13**.

We previously reported that the dehydrogenation of *p*-cresol by the one electron transfer agent ferric chloride in acidic solution yielded three new ketonic products **5–7** and a dimeric ether **3** in addition to **1**, **2**, and Pummerer's ketone **4**.[2] In that communication we reported that **5** was isolated from the peroxide–peroxidase dehydrogenation of *p*-cresol but not hemiketals **6** and **7**. Compounds **1**, **2**, and **4** were isolated earlier from the ferric chloride,[3–5] alkaline ferricyanide[6] and peroxide–peroxidase[7] dehydrogenation of *p*-cresol.