The Chloroiodination of Deactivated Olefins with Antimony(V) Chloride–Iodine and Iodine Monochloride

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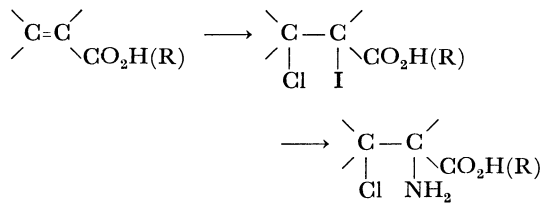
By the reactions of olefins with an equimolar mixture of $SbCl_5$ and I_2 in carbon tetrachloride, various chloroiodoalkanes are obtained in fair to good yields. This method is applicable to various deactivated olefins, the reactions of which do not proceed by the reported method using a mixture of $CuCl_2$ and I_2. Iodine monochloride can aslo be used for this reaction, but in this case both the yield and the regiospecificity of the products are sometimes inferior.

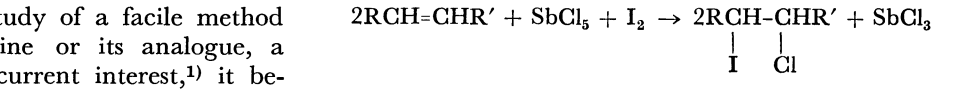
During the course of the study of a facile method for preparing β-chloro-L-alanine or its analogue, a useful "suicide" substrate of current interest,[1] it became necessary for us to prepare α-iodo-β-chloro carboxylic acid or its ester as a precursor, which may be obtained by the chloroiodination of the corresponding α,β-unsaturated carboxylic acid or its ester. Baird *et al.*[2] have reported an efficient chloroiodination of olefins by using $CuCl_2$ and I_2 to produce chloroiodoalkanes, which have not generally been prepared by



the addition of preformed iodine monochloride to olefins. The scope of this reaction is, however, restricted to olefins which have electron-donating substituents, such as alkyl and acetoxyl groups. It has previously been reported that a facile bromochlorination of olefins occurred with a mixture of antimony(V) chloride and bromine; this method is applicable to various deactivated olefins, such as fumaric and maleic esters and 1,2-dichloroethylene.[3] We have now found that a mixture of antimony(V) chloride and iodine can effect the chloroiodination of such deactivated olefins in carbon tetrachloride. It has also been shown that commercial iodine monochloride itself works as a chloroiodinating agent for such olefins, although the yield and the selectivity of the products were sometimes lower than with the $SbCl_5$–I_2 system. As one of a series of our studies of halogenation by the use of antimony(V) chloride,[3,4] we wish here to describe the details of the chloroiodination of olefins by using $SbCl_5$–I_2.

Results and Discussion

The reactions of activated olefins, such as 1-hexene, cyclohexene, and vinyl acetate, with an equimolar mixture of $SbCl_5$ and I_2 in carbon tetrachloride at the reflux temperature gave the corresponding chloroiodoalkanes in good to high yields, as in the cases with $CuCl_2$ and I_2. The stoichiometry of the reaction is given by Eq. 1. Here, the generation of two moles



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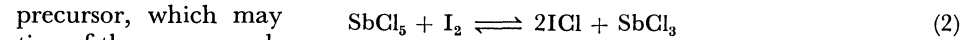

(2)

of ICl can be explained by assuming Eq. 2, as in the case of bromochlorination with $SbCl_5$ and Br_2.[3]

The application of this reaction to several deactivated olefins, such as α,β-unsaturated esters and nitriles, resulted in the formation of the expected chloroiodoalkanes in fair to good yields; this is in sharp contrast to the reaction with $CuCl_2$–I_2 system, which did not afford those products from several α,β-unsaturated esters under similar reaction conditions. Some typical results are shown in Table 1. As can be seen from the table, the yields of the products increased when the reaction temperature was raised in the case of α,β-unsaturated esters, while in the case of α,β-unsaturated nitriles the reaction at room temperature gave the most satisfactory results, though the yield was still low. In the latter case, the tarry compounds became almost the sole products at the reflux temperature, while only a trace amount of product was obtained at 0—5 °C.

Iodine monochloride is generally known as an iodinating agent for activated aromatic compounds, and there seem to have been no thorough studies of the chloroiodination of olefins by this reagent.[5] There is even a description in the literature[2] of how chloroiodoalkanes have not generally been prepared by the addition of iodine monochloride to olefins because of the dissociable nature of ICl, which frequently leads to high yields of unstable diiodides, along with small amounts of the desired product. However, when we treated the above olefins with commercial iodine monochloride, the desired chloroiodoalkanes were obtained; the yields of the products were even better for some olefins than those in the $SbCl_5$–I_2 system in the reaction at room temperature. The results are also listed in Table 1. When styrene was used as the substrate, chloroiodination proceeded with iodine monochloride, while (1-chloroethyl)benzene and polymeric tars were obtained by the use of $SbCl_5$–I_2 under the several sets of conditions we employed. It has previously been reported[2] that (1,2-dichloroethyl)benzene was the sole product in the reaction of styrene with $CuCl_2$–I_2. The isomer distributions of the products obtained

Table 1. Chloroiodination of various olefins in carbon tetrachloride

Olefin(25 mmol); halogenating agent, $SbCl_5$ or $CuCl_2$(12.5 mmol)+I_2(12.5 mmol), ICl(25 mmol); solvent(50 ml), CCl_4.

Olefin	Temp °C	Time h	Product	Yield/%[a] $SbCl_5+I_2$	ICl	$CuCl_2+I_2$
CH_2=$CHCO_2Et$	25	1	$CH_2ClCHICO_2Et$ (I) $CH_2ICHClCO_2Et$ (II)	31[b]	53[b]	0
CH_2=$CHCO_2Et$	76	1	$CH_2ClCHICO_2Et$ (I) $CH_2ICHClCO_2Et$ (II)	86[c,d]	69[e]	trace
trans-CH_3CH=$CHCO_2Me$	25	1	$CH_3CHClCHICO_2Me$ (I) $CH_3CHICHClCO_2Me$ (II)	51[g]	80[f]	0
trans-CH_3CH=$CHCO_2Me$	76	1	$CH_3CHClCHICO_2Me$ (I) $CH_3CHICHClCO_2Me$ (II)	63[g]		
CH_2=CHCN	25	1	$CH_2ClCHICN$	10	trace	
CH_2=$C(CH_3)CN$	25	1	$CH_2ClCI(CH_3)CN$ (I) $CH_2ICCl(CH_3)CN$ (II)	12[h]	8[h]	
cis-EtOOCCH=CHCOOEt	25	1	*threo*-EtOOCCHICHClCOOEt	13	18	
cis-EtOOCCH=CHCOOEt	76	3	*threo*-EtOOCCHICHClCOOEt	50	33	
trans-EtOOCCH=CHCOOEt	25	1	*erythro*-EtOOCCHICHClCOOEt	6	10	
trans-EtOOCCH=CHCOOEt	76	3	*erythro*-EtOOCCHICHClCOOEt	60	11	0
$PhCH$=CH_2	25	2	$PhCHClCH_2I$		79[e]	
$PhCH$=CH_2	25	16	$PhCHClCH_3$	34[e,i]		
n-C_4H_9CH=CH_2	30	0.2	n-$C_4H_9CHClCH_2I$ (I) n-$C_4H_9CHICH_2Cl$ (II)	30[e,j]	75[k]	91[h,l]
Cyclohexene	76	0.2	*trans*-1-Chloro-2-iodocyclohexane	94[e,m]		95[l]
CH_2=$CHOAc$	55	0.2	$CH_2ICH(Cl)OAc$	87[e]		88[l]

a) Determined by GLC unless otherwise stated. b) Ratio of I : II not known. c) Isolated yield. d) I : II=82 : 18. e) I : II=75 : 25. f) I : II=92 : 8. g) I : II=100 : 0. h) I : II=80 : 20. i) No $PhCHClCH_2I$; tarry products were formed. j) I : II=73 : 27. k) I : II=66 : 34. l) Ref. 2. m) Ref. 3.

from unsymmetrical olefins which were determined by ^{13}C NMR and/or GLC showed that I^+ attacked the electron-rich carbon solely or predominantly, as had been expected. For example, the chloroiodination of ethyl acrylate, methyl crotonate, acrylonitrile, and methacrylonitrile with $SbCl_5$–I_2 gave the corresponding chloroiodoalkanes with a selectivity of more than 80%. As to the isomer distributions of the products, there are not so many differences between the reaction with $SbCl_5$–I_2 and that with ICl, though the selectivity is slightly higher in the case of the $SbCl_5$–I_2 system. The reaction with $SbCl_5$–I_2 seems to involve the *in situ* formation of ICl by Eq. 2, followed by the attack of the ICl thus formed on olefins. Here, iodine monochloride may be activated by the $SbCl_5$ or $SbCl_3$ present in the reaction system to give more polarized species, as has been clarified in the chloroiodination of acetylenes with the same system.[4b]

Experimental

The GLC analyses were conducted on a Shimadzu 4CMPF apparatus, using Silicone DC QF-1 (1 and 3 m) and EGSS-X (1 m) columns (carrier gas, N_2). The ^1H NMR spectra were recorded with a JEOL MH-100 (100 MHz) and a Varian EM-360 (60 MHz) spectrometer in CCl_4, using TMS as the internal standard. The ^{13}C NMR spectra were recorded in the pulsed Fourier transform mode on a JEOL FX-100 spectrometer operating at 25.15 MHz in $CDCl_3$, using TMS as the internal standard.

Materials. All the starting materials—olefins, $SbCl_5$, $SbCl_3$, $CuCl_2$, I_2, iodine monochloride, and CCl_4—were commercially available and were used without further purification. Chloroiodoalkanes from cyclohexene, vinyl acetate, and 1-hexene were confirmed by a comparison of the ^1H NMR spectra and retention times on GLC with those of authentic samples prepared by the reported method.[2] All the other chloroiodoalkanes were isolated by distillation. Commercial 1-phenylethyl chloride was used as an authentic sample for GLC and ^1H NMR.

Syntheses of Chloroiodoalkanes. A typical experimental procedure and the spectral data and boiling points of the products are shown below.

Chloroiodination of Ethyl Acrylate with Antimony(V) Chloride–Iodine. To a dark brown, homogeneous solution of $SbCl_5$ (7.5 g, 25 mmol) and I_2 (6.3 g, 25 mmol) in CCl_4 (100 ml), ethyl acrylate (5.0 g, 50 mmol) was added, drop by drop, at the reflux temperature over a 10-min period, during which the color of the solution turned to purple. After stirring for 1 h, the reaction mixture was treated with water, and the white-to-pale yellow inorganic precipitate thus formed was removed by filtration. The CCl_4 layer was separated from the aqueous one, washed with aq $Na_2S_2O_3$, and dried over Na_2SO_4, and the solvent was evaporated. A liquid fraction boiling at 105 °C/20 mmHg (11.2 g) was collected; it consisted of ethyl 3-chloro-2-iodopropionate(I) and ethyl 2-chloro-3-iodopropionate(II) (I:II=82:18). The structural determination was carried out by means of ^1H and ^{13}C NMR and elemental analysis, while the isomer ratio was determined by ^{13}C NMR by comparing the peak intensities of the ethyl-group carbons of the two compounds. Found: C, 23.10; H, 2.89%. Calcd for $C_5H_8O_2ClI$: C, 22.88; H, 3.07%. ^1H NMR (CCl_4): δ 1.3 (t, 3H), 3.25—4.80 (m, 5H). ^{13}C NMR ($CDCl_3$): δ for I, 13.6 ($\underline{CH_3}$,

q), 16.9 (CHI, d), 44.7 (CH_2Cl, t), 62.1 (OCH_2, t), 168.7 (CO_2, s); δ for II, 2.5 (CH_2I, t), 13.9 (CH_3, q), 54.8 (CHCl, d), 62.4 (OCH_2, t), 168.7 (CO_2, s).

Methyl 3-Chloro-2-iodobutanoate(I) and Methyl 2-Chloro-3-iodobutanoate(II). Bp of I, 63—66 °C/3 mmHg. ^{1}H NMR of I (CCl_4): δ 1.7—1.9 (m, 3H), 3.73 (s, 3H), 4.17—4.45 (m, 2H). ^{13}C NMR ($CDCl_3$): δ for I, 24.6 (CH_3, q), 26.4 (CHI, d), 52.9 (OCH_3, q), 56.1 (CHCl, d), 169.4 (CO_2, s); δ for II, 22.1 (CHI, d), 24.6 (CH_3, q), 52.9 (OCH_3, q), 61.9 (CHCl, d), 169.4 (CO_2, s). Found: C, 23.17; H, 3.05%. Calcd for $C_5H_8O_2ClI$: C, 22.88; H, 3.07%.

3-Chloro-2-iodopropionitrile. Bp 95 °C/10 mmHg. ^{1}H NMR ($CDCl_3$): δ 3.87 (d, 1H, CH_2Cl), 3.90 (d, 1H, CH_2Cl), 4.52 (dd, 1H, CHI). ^{13}C NMR ($CDCl_3$): δ −5.4 (CHI, d), 45.2 (CH_2Cl, t), 116.9 (CN, s).

3-Chloro-2-iodo-2-methylpropionitrile(I) and 2-Chloro-3-iodo-2-methylpropionitrile(II). Bp of a mixture of I and II (I:II=80:20 by GLC), 40—44 °C/5 mmHg. ^{1}H NMR (CCl_4): δ 2.08 (s, CH_3 for II), 2.30 (s, CH_3 for I), 3.62 and 3.81 (d, J=10 Hz, CH_2 for II), 3.86 and 4.14 (d, J=12 Hz, CH_2 for I). ^{13}C NMR ($CDCl_3$): δ for I, 13.2 (s, quarternary C), 30.7 (q, CH_3), 52.9 (t, CH_2Cl), 119.8 (s, CN); δ for II, 11.7 (t, CH_2I), 30.0 (q, CH_3), 68.2 (s, quarternary C), 117.4 (s, CN).

Diethyl threo- *and* erythro-*2-chloro-3-iodosuccinate.* *threo*-Isomer: Bp 84 °C/3 mmHg. ^{1}H NMR (CCl_4): δ 1.3 (t, 6H), 4.18 (q, 4H), 4.4 (d, 1H), 4.8 (d, 1H). *erythro*-Isomer: Bp 100 °C/2 mmHg. ^{1}H NMR (CCl_4): δ 1.27 (t, 3H, CH_3), 1.30 (t, 3H, CH_3), 4.27 (q, 2H, CH_2), 4.30 (q, 2H, CH_2), 4.60—4.70 (m, 2H, CHCl and CHI).

(1-Chloro-2-iodoethyl)benzene. To a brown solution of iodine monochloride (4.05 g, 25 mmol) in CCl_4 (70 ml), we added styrene (2.61 g, 25 mmol) at 20 °C, after which the mixture was stirred for 2 h. After a usual work-up procedure, distillation afforded the product; 5.3 g (79% yield); bp 113 °C/6 mmHg, mp 41 °C (lit,[6] mp 46 °C). ^{1}H NMR ($CDCl_3$): δ 3.67 (d, 1H, CH_2I), 3.69 (d, 1H, CH_2I), 5.00 (dd, 1H, CHCl), 7.3 (m, 5H).

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