

Reaction of pentaarylantimony with acid halide, aldehyde and ketone

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Abstract

Pentaarylantimony (pentaphenylantimony, penta-*p*-tolylantimony and penta-*p*-chlorophenylantimony) was found to be a mild arylation reagent. The arylation was chemoselective toward aromatic acid halides to give the corresponding aromatic ketones. No direct addition to ketone and acid anhydride occurred. Arylation reactions of aldehyde or ketone were promoted by the addition of Lewis acid. The nucleophilicities of aromatic antimony compounds depend on the number of antimony–aromatic carbon bonds.

Keywords: Pentaarylantimony; Acid halide; Aldehyde; Ketone; Chemoselective reaction; Antimony

1. Introduction

The reaction behaviors of organoantimony compounds have been recently applied for synthetic organic reactions [1]. Most of studies are performed using trivalent antimony compounds such as triphenyl- [2] and tributylstibine [3] and pentavalent stibonium compounds such as tetraphenylstibonium iodide [4] and methoxide [5]. Recently it was found [3,6] that alkyl organoantimony compounds with five antimony–carbon bonds exhibited unique reactivities for carbon–carbon bond formation different from other 15 group elements such as phosphorus [7], arsenic [8] and bismuth [9]. Although these observations presage novel synthetic reactions using pentavalent organoantimony compounds, their utilization in situ is inevitable because of their extremely low stability so that they can be identified only by using mass spectrometry [10]. On the other hand, aromatic organoantimony compounds bearing five antimony–aromatic carbon bonds (pentaarylantimony) are comparatively stable and can be isolated and purified by recrystallization [11–13]. Although their reaction behaviors and synthetic applications were seldom examined because of their relatively poor reactivity [14], their stable character is more advantageous in the fundamental studies on the properties of organoantimony compounds

with five antimony–carbon bonds. In this paper, we wish to report the reactivities of pentaarylantimony to acid halides, aldehydes and a ketone.

2. Results and discussion

The results of the reaction of pentaarylantimony with acid halides



are summarized in Table 1. Without any additives pentaphenylantimony [11] reacted with benzoyl chloride to give benzophenone in 79% yield (run 1). This is the first example of the coupling reaction of pentaarylantimony with acid halides, although dipropynyltriphenylantimony [15] and triphenyldimethylantimony [6] have been reported to react with acid halides. Acetonitrile was the solvent of choice, and neither benzene (45%) nor DMF (~0%) were suitable. In contrast to pentaphenylantimony, triphenylstibine and tetraphenylstibonium bromide gave no benzophenone. Although other *para*-substituted benzoyl chloride derivatives and cinchonoyl chloride also afforded the corresponding ketones in good yields (runs 2–5), alkyl derivatives such as hexanoyl chloride gave the coupling product only in low yield (run 6).

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Table 1
Reaction of pentaarylantimony with acid halides^a

run	Antimony	Acid halide	Yield (%) ^{b,c}
1	Ph ₅ Sb	PhCOCl	79
2	Ph ₅ Sb	<i>p</i> -ClC ₆ H ₄ COCl	77
3	Ph ₅ Sb	<i>p</i> -NO ₂ C ₆ H ₄ COCl	78
4	Ph ₅ Sb	<i>p</i> -MeOC ₆ H ₄ COCl	83
5	Ph ₅ Sb	PhCH = CHCOCl	64 (33)
6	Ph ₅ Sb	<i>n</i> -C ₅ H ₁₁ COCl	13
7	<i>p</i> -Tol ₅ Sb	PhCOCl	35
8 ^d	<i>p</i> -Tol ₅ Sb	PhCOBr	68
9 ^e	(<i>p</i> -ClC ₆ H ₄) ₅ Sb	PhCOCl	76
10	Ph ₅ Sb	PhCOF	tr (39)
11 ^d	Ph ₅ Sb	PhCOBr	87
12	Ph ₅ Sb	EtOCOCOCI	~100
13	LiSbPh ₆	<i>n</i> -C ₅ H ₁₁ COCl	28 (18)
14 ^f	Ph ₅ Sb	<i>n</i> -C ₅ H ₁₁ COCl	50

^a Reaction conditions: antimony/acid halide = 1/3 mmol, solv. acetonitrile 1 ml, 80°C, 24 h.

^b Determined by GLC based on an aryl group in pentaarylantimony.

^c Yields of biphenyl were in parentheses; in other runs, trace amounts of biphenyl were obtained.

^d 3 h.

^e Penta-*p*-chlorophenylantimony slightly dissolved in acetonitrile.

^f Tetrakis (triphenylphosphine) palladium (0.05 mmol) was added.

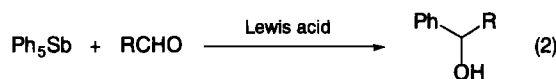
Para-substituted aromatic antimony compounds, penta-*p*-tolylantimony [12] and penta-*p*-chlorophenylantimony [13] were also applicable to give the corresponding ketones in moderate to good yields (runs 7–9). The effect of the substituents in the aryl group to the reactivity of pentaarylantimony was clearly observed. In the case of the homogeneous benzene solvent reaction, the yields of the products with benzoyl chloride increased in the following order, penta-*p*-tolylantimony (29%) < pentaphenylantimony (45%) < penta-*p*-chlorophenylantimony (79%). This tendency is in accord with the stability of aryl anion. The comparison of reactivity of three acid halides, benzoyl fluoride, chloride and bromide is also suggestive (runs 1, 10, 11). The good agreement of the reactivity order, Br > Cl > F, was observed between pentaarylantimony, and organozinc and -cadmium reagents [16]. In the cases of zinc and cadmium reagents, the coordination of carbonyl oxygen to the metal is excluded, and a direct substitution reaction is suggested [16]. As the Lewis acidity of pentaarylantimony is thought to be very poor [17], the reaction of pentaarylantimony with acid halides seems to proceed in a nucleophilic manner similar to organozinc and -cadmium reagents.

This arylation procedure could be expanded to ethyl oxalyl chloride, yielding ethyl benzoylformate quantitatively (run 12). Ethyl benzoylformate is very susceptible to organometallic compounds, even those such as organocadmium reagents which are known to be versatile for chemoselective ketone synthesis from acid halides [18]. Ethyl benzoylformate was recovered quan-

titatively in the reaction with an equimolar amount of pentaphenylantimony under the same reaction conditions. The formation of triphenylmethanol was not naturally observed at all in the reaction of benzoyl chloride with pentaphenylantimony. Benzoic and phthalic anhydride were also recovered completely, while it was known that they readily reacted with organocadmium reagents to afford the corresponding ketones [16]. Furthermore, a nitro function tolerated this arylation by pentaphenylantimony, furnishing the corresponding phenyl ketone in a good yield (run 3). This high chemoselectivity has not been observed in other organometallic compounds.

For the sake of improving the yield of the coupling product with hexanoyl chloride, we attempted two modifications. Pentaphenylantimony is known to react with phenyllithium to form lithium hexaphenylantimonate [11]. When this ate-complex was used for the coupling reaction, the product yield increased from 13% to 28% (run 13), although it is hard to dissolve in acetonitrile. On the other hand, the addition of tetrakis(triphenylphosphine)palladium obviously improved the yield of the *n*-pentyl phenyl ketone (run 14) [18]. It is well known that the coupling reaction of various organometallic compounds with acid halides is catalyzed by palladium complexes [19].

The reaction of pentaphenylantimony with aldehydes was next studied



and the results are summarized in Table 2. Although no benzhydrol was obtained in the absence of any promoter (run 1), the nucleophilic addition to aldehydes was effected by Lewis acid. Benzaldehyde (run 2) and *n*-hexanal (run 6) produced the corresponding phenylated alcohols in 95 and 56% yields, respectively, in the presence of an equimolar amount of titanium tetrachloride to the aldehydes. Boron trifluoride etherate also

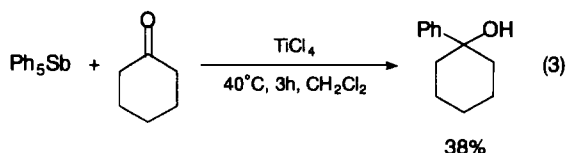
Table 2
Reaction of pentaphenylantimony with aldehydes^a

Run	Aldehyde	Lewis acid	Temp.	Yield (%) ^b
1	PhCHO	–	40°C	0
2	PhCHO	TiCl ₄	–78°C → rt	95
3	PhCHO	BF ₃ ·Et ₂ O	–78°C → rt	54
4	PhCHO	AlCl ₃	–78°C → rt	7
5	PhCHO	SnCl ₄	–78°C → rt	0
6	<i>n</i> -C ₅ H ₁₁ CHO	TiCl ₄	–78°C → rt	56

^a Reaction conditions: antimony/aldehyde/Lewis acid = 1.5/0.5/0.5 mmol, solv. dichloromethane 4 ml, 3 h.

^b Determined by GLC based on a phenyl group in pentaphenylantimony.

promoted the reaction moderately (run 3). However, other Lewis acids such as aluminum chloride and tin tetrachloride were not effective at all (run 4, 5). Even in the case of aldehyde, neither triphenylstibine nor tetraphenylstibonium bromide gave any benzhydrol. On the other hand, 1-phenylcyclohexanol was obtained in a modest yield (38%) in dichloromethane at reflux for 3 h



although cyclohexanone did not react with pentaphenylantimony under similar conditions to the reaction with aldehyde.

The best yield (95%; run 2) of benzhydrol was observed in the reaction where benzaldehyde and titanium tetrachloride were first mixed to form a complex. The addition of benzaldehyde to the mixed solution of pentaphenylantimony and titanium tetrachloride afforded the product in low yield (18%). Moreover, no benzhydrol was obtained in the reaction of titanium tetrachloride with the solution of pentaphenylantimony and the aldehyde. It seems that the formation of the complex of aldehyde with Lewis acid is essential to accomplish this addition reaction. Titanium tetrachloride-mediated reaction of pentaphenylantimony with aldehyde may proceed by nucleophilic attack of one phenyl group of pentaphenylantimony on the carbonyl carbon of aldehyde activated by the coordination of titanium tetrachloride (Fig. 1).

From the results of the reactions using three types of organoantimony compound, the nucleophilicities of aryl groups of those organoantimony compounds seem to be different. Triarylantimony is regarded as a base rather than a nucleophile. In the case of tetraarylstibonium bromide, the anionic species is bromide and all aryl groups are included in the cationic stibonium moiety. Therefore, the nucleophilicity of these aryl groups seems

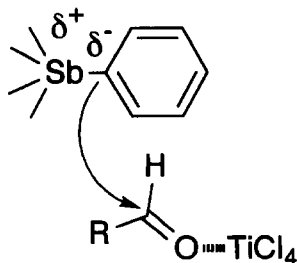


Fig. 1. A plausible reaction scheme of pentaphenylantimony with aldehyde mediated by titanium tetrachloride.

to be very poor. On the other hand, aryl groups of pentaarylantimony have enough nucleophilicity. However, the reaction of one aryl group of pentaarylantimony forms tetraarylstibonium-type compounds which are inactive for the reaction. Therefore, only one aryl group of pentaarylantimony reacted in all cases.

In conclusion, arylation utilizing pentaarylantimony, which has been hardly employed in organic synthesis, could be applicable for acid halides, aldehydes or a ketone. The direct arylation has a high chemoselectivity to aromatic acid halides. On the other hand, the reactions with aldehydes or a ketone were promoted by the addition of titanium tetrachloride.

3. Experimental section

3.1. Materials

All acid halides, aldehydes, Lewis acids and cyclohexanone, which are commercially available, were used without further purification. All solvents were used after distillation. Triphenylantimony was a commercial product, which was purified by recrystallization (ethanol). Tetraphenylstibonium bromide was prepared by the described method [20]. Pentaphenylantimony, penta-*p*-tolylantimony and penta-*p*-chlorophenylantimony were obtained by a modified method [21]. Tetrakis(triphenylphosphine)palladium was purchased from Tokyo Kasei Industry. NMR spectra were determined on a JEOL α -500 (500 MHz) spectrometer.

3.1.1. Pentaphenylantimony

The THF solution (50 ml) of triphenylantimony dibromide (38 mmol) obtained from triphenylantimony and bromine [22] was added dropwise to a THF solution (100 ml) of phenylmagnesium bromide (80 mmol) for 30 min in ice bath. The resulting solution was refluxed for 3 h. After cooling, the THF solution was poured into a 2 M HCl aqueous solution (130 ml) with some ice. The precipitate formed was filtrated, washed with water and dried under reduced pressure. The crude product was recrystallized from acetonitrile; purified isolated yield was 80%; m.p. 170–172 °C (lit. 168.5–170 °C) [11]; $^1\text{H NMR}$ (CDCl_3): δ 7.0–7.2 (m, Ph) ppm. Penta-*p*-tolylantimony and penta-*p*-chlorophenylantimony were obtained in a similar manner to pentaphenylantimony.

3.1.2. Penta(*p*-tolyl)antimony

Purified isolated yield was 55%; m.p. 201–203 °C (hexane) (lit. 189 °C) [12], $^1\text{H NMR}$ (CDCl_3): δ 2.3 (s, 15H, CH_3); 7.0–7.1 (m, 10H, C_6H_4); 7.2–7.3 (m, 10H, C_6H_4) ppm.

3.1.3. Penta(*p*-chlorophenyl)antimony

Purified isolated yield was 26%, mp. 218–222 °C (benzene/petroleum ether) (lit. 197 °C) [13], ¹H NMR (CDCl₃): δ 7.0–7.1 (m, C₆H₄) ppm.

3.2. Reaction procedure

Typical procedure of the reaction of pentaarylantimony with acid halide

To a solvent solution (1 ml) of pentaarylantimony (1 mmol) was added an acid halide (3 mmol) at room temperature. The resulting mixture was stirred for 24 h at 80 °C under nitrogen atmosphere. After removing the solvent under reduced pressure, the residue was subjected to silica-gel column chromatography, giving the crude product (benzene). Purification was performed by recrystallization using benzene/hexane (benzophenone, *p*-chlorobenzophenone, *p*-nitrobenzophenone, *p*-methoxybenzophenone, chalcone) or distillation (*n*-pentyl phenyl ketone and ethyl benzoylformate). All products were identified by ¹H NMR and GLC by reference to commercial standards.

Typical procedure of the reaction of pentaphenylantimony with aldehyde

To the dichloromethane solution (2 ml) of an aldehyde (0.5 mmol) was added at –78 °C a Lewis acid (0.5 mmol), and then the dichloromethane solution (2 ml) of pentaphenylantimony (1.5 mmol) was mixed. Temperature was gradually increased and finally reached room temperature after 3 h. The resulting mixture was washed with an aqueous solution of sodium bicarbonate and organic materials were extracted by diethyl ether. The organic layer was dried over anhydrous magnesium sulfate. After removing the solvent under reduced pressure, the residue was subjected to silica-gel column chromatography, giving the crude product (benzene). Purification was performed by recrystallization using benzene/hexane (benzhydrol) or distillation (1-phenyl-1-hexanol). All products were identified by ¹H NMR and GLC satisfactorily.

The procedure of the reaction of pentaphenylantimony with cyclohexanone

To the dichloromethane solution (2 ml) of cyclohexanone (0.5 mmol) was added at room temperature titanium tetrachloride (0.5 mmol), and then the dichloromethane solution (2 ml) of pentaphenylantimony (1.5 mmol) was mixed. The resulting solution was refluxed for 3 h. The work-up procedure was the same as that in the reaction with aldehyde.

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