Direct Reaction of Aryl Iodides with Activated Aluminium Powder and Reactions of the Derived Aryl Sesquiiodides

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Received 10 November 2009

Dedicated to Prof. G. Pattenden on the occasion of his 70th birthday

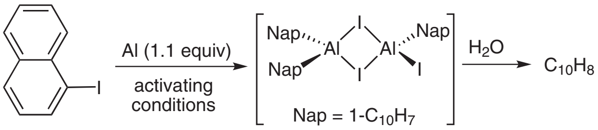
Abstract: High temperature (110–120 °C) direct reaction of ArI (Ar = Ph, 1-$C_{10}H_7$, 3-Tol) with aluminium powder in the presence of $HgCl_2$ (1 mol%) or liquid gallium metal (10 mol%) leads to quantitative conversion to the aryl sesquiiodides $Al_2Ar_3I_3$. The latter, highly Lewis acidic, compounds are effective in opening of cyclic ethers and direct ester to amide conversions.

Key words: organometallic reagents, Lewis acids, amides, halides, electron transfer

Elemental aluminium is the most abundant metal in the Earth's crust and has been widely available since the introduction of the Hall–Héroult process in the 1890s. However, despite its potential as a reducing agent (Al^{3+}/Al^0 –1.66 volts) its use in synthetic organic chemistry has been limited by its ready passivation through the formation of inert surface oxide coatings (Al-O ca. 101 kcal mol^{-1}).[1] Amalgam formation has been used as a method to activate aluminium; Al-Hg acts as an exemplary reducing agent for sensitive nitro[2,3] and sulfoximine[4] compounds. Aluminium metal also serves as a terminal reductant for Barbier-type reactions of aldehydes,[5] carboxylic esters,[6] Baylis–Hillman-derived acetates[7] and imines.[8] In many cases the presence of redox catalysts is required to promote the reaction including, Sb^{III}, Fe^{II}, Ni^{II}, Cr^{III} and Pb^{II}. Formation of isolable *sp*^{3} organoaluminiums is dominated by the industrial (Hüls) process for the sesquichlorides $Al_2R_3Cl_3$ (R = Me, Et).[9] Through the use of reactive allylic halides the synthetic utility of such compounds has been extended to 1,2-additions of allylic sesquihalides to carbonyls[10] and imines.[11,12]

In contrast, direct preparations of *sp*^{2} sesquihalides are limited to two papers. An early report suggests PhI reacts with Al at very high temperatures providing a very poor conversion,[13] while Ti–Al alloy is claimed to allow the formation of $Al_2Ph_3Br_3$.[14] As such species are expected to be potentially useful Lewis acids we sought to identify a quick, technically simple approach to their preparation. In preliminary reactions with 1-naphthyliodide, aluminium powder of mesh size ca. 200 (Acros) was found to be the most convenient reagent (Table 1). In the absence of any promoters, unlike Grosse,[13] we could not attain any insertion even after prolonged heating (entry 1). However, the presence of catalytic amounts of $HgCl_2$ led to high yields of naphthalene in the presence or absence of solvent (entries 2–4). Under these conditions reduction of $HgCl_2$ and subsequent Al-amalgam formation is known to take place.[9] As the use of even catalytic amounts of mercury is not always acceptable in organic syntheses we sought a complimentary activation method. It is known that gallium forms a 97:3 alloyed phase with aluminium that shows enhanced redox properties under certain conditions.[15] Use of liquid Ga allowed sesquiiodide formation (entry 5), albeit at a slower rate than that observed with $HgCl_2$ activation.[16] Neither Hg or Ga activation worked for 1-$BrC_{10}H_7$, nor did other promoters tried (PbI_2, $TiCl_4$).

Table 1 Optimization of C–I Insertion Process



Entry	Conditions	Yield of $C_{10}H_8$ (%)[a]
1	Al, neat $C_{10}H_7I$, 120 °C, 2–350 h	0
2	Al, neat $C_{10}H_7I$, 120 °C, 3 h, $HgCl_2$ (1 mol%)	>95
3	Al, $C_{10}H_7I$ (1 M in toluene), 110 °C, 3.5 h, $HgCl_2$ (1 mol%)	89
4	Al, $C_{10}H_7I$ (1 M in *p*-xylene), 138 °C, 3.5 h, $HgCl_2$ (1 mol%)	91
5	Al, neat $C_{10}H_7I$, 120 °C, 20 h, Ga (10 mol%)	>95

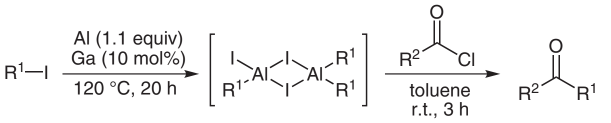
[a] Determined by GC against internal standard (tridecane).

To confirm that the sesquiiodides were being formed under these reaction conditions, a number of them were intercepted with representative acyl chlorides (Table 2).[17]

In all cases (entries 1–8) near quantitative yields of the expected carbonyl compounds were attained. Attempts to extend this chemistry to more functionalised sesquiiodides (containing OMe, Ac or CN groups) resulted in low to negligible yields. The sesquiiodides prepared by our procedure are intensely Lewis acidic. For example, cyclic ethers underwent spontaneous ring-opening reactions in the presence the PhI-derived reagent leading to near quan-

SYNLETT 2010, No. 4, pp 0636–0638
Advanced online publication: 07.01.2010
DOI: 10.1055/s-0029-1219179; Art ID: D32709ST

Table 2 Reaction of Sesquiiodides with Acid Chlorides

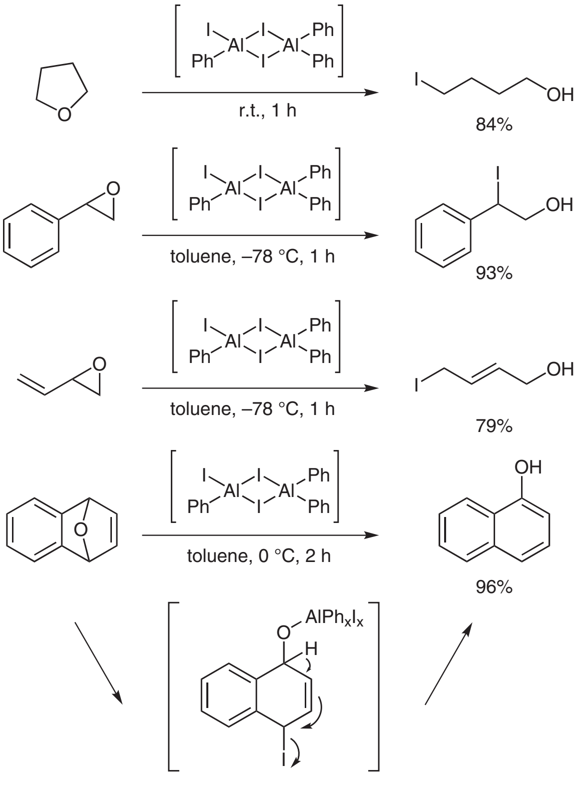


Entry	R^1	R^2	Yield (%)[a]
1	Ph	Ph	97
2	1-naphthyl	Ph	96
3	3-Tol	Ph	91
4	Ph	Bn	83
5	Ph	$3\text{-}BrC_6H_4$	98
6	Ph	$4\text{-}BrC_6H_4$	79
7	1-naphthyl	Bn	80
8	1-naphthyl	$3\text{-}BrC_6H_4$	96

[a] Isolated yields. Equivalent yields were realised in reagents generated from $HgCl_2$ catalysis.

titative yields of iodide-transfer products (Scheme 1). In no case was phenyl transfer observed.

In line with this behaviour $Al_2Ph_3I_3$ acted as a demethylating reagent for anisole, but its performance was not superior to BBr_3; additionally, attempts to prepare these sesquiiodides in ethereal solvents failed. In an attempt to mitigate this extreme Lewis acidity $Al_2Ph_3I_3$ was reacted with DABCO at low temperature leading to an instantaneous white precipitate of $(DABCO)Al_2Ph_3I_3$ (Figure 1).



Scheme 1

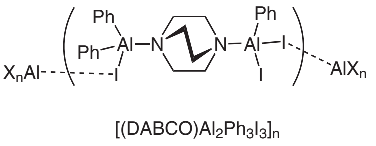
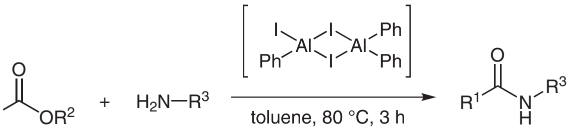


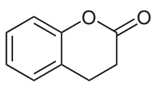
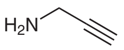
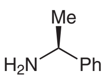
Figure 1

While the ^1H NMR spectrum is in accord with this formulation the material's low solubility limits its utility compared to its commercial $AlMe_3$ analogue.[18–20] However, like the latter species $(DABCO)Al_2Ph_2I_3$ shows a similar degree of air stability and may be handled on the bench for short periods.

Due to its ease of preparation and very high Lewis acidity we speculated that $Al_2Ph_3I_3$ would promote the direct formation of amides from methyl esters. An equivalent reaction using $AlMe_3$ is known,[21] but an ability to tune the Lewis acidity at aluminium is not available in this case. The phenyl sesquiiodide proves to be an effective reagent (Table 3).[22]

Table 3 $Al_2Ph_3I_3$-Promoted Formation of Amides



Entry	R^1	R^2	R^3	Yield (%)[a]
1	Ph	Me	Bn	97
2	Bn	Et	Bn	98
3	*t*-Bu	Et	Bn	98
4			Bn	83
5	Ph	Me	*t*-Bu	96
6	Ph	Me		56
7	Ph	Me	Ph	98
8	Ph	Me		98

[a] Isolated yield.

In all but one case (entry 6) highly effective direct transformations were attained. We could not detect any carboalumination products in reactions using propargylic amine; polymerisation events seem to account for the missing mass.

In conclusion we have developed a convenient route to the preparation of rare, highly Lewis acidic, *sp*^{2} aryl sesquiiodides. Such compounds, which are not easily accessed in a 'salt-free' form via transmetallation reactions, constitute an interesting, tunable addition to the organic Lewis acid family.

Acknowledgment

We thank the Engineering and Physical Sciences Research Council for partial support of this programme through Grant EP/G026882/1. X.T. thanks the Marie Curie Office of the European Commission for support through contract MEST-CT-2005-019780 (INDACCHEM).

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(16) **General Procedure for the Synthesis of Sesquihalide**; *Method 1*: Aluminium powder (81 mg, 3 mmol) and $HgCl_2$ (5 mg, 0.02 mmol) were added to a dry argon-flushed Schlenk tube. Organohalide (2 mmol) was added and the reaction was stirred at 120 °C for 3 h. Anhydrous toluene (1 mL) was added and the mixture was stirred vigorously for 5 min. The reaction mixture was allowed to cool to r.t. and left for 30 min for the excess aluminium metal to settle. The light brown supernatant solution of organoaluminium sesquihalide was ready to use. *Method 2*: Aluminium powder (59 mg, 2.2 mmol) and Ga (14 mg, 0.2 mmol) were added to a dry argon-flushed Schlenk tube. Organohalide (2 mmol) was added and the reaction was stirred at 120 °C for 20 h. Anhydrous toluene (1 mL) was added and the mixture was stirred vigorously for 5 min. The reaction mixture was allowed to cool to r.t. and left for 30 min for the excess aluminium metal to settle. The light brown supernatant solution of organoaluminium sesquihalide was ready to use.

(17) **General Procedure for Reactions of Sesquihalide and Acetyl Chloride**: Acetyl chloride (1 mmol) was dissolved in anhydrous toluene (2 mL), and sesquihalide (1 mmol) prepared by method 2 was added. The reaction mixture was stirred at r.t. for 3 h. The reaction was quenched with HCl (2 M) and extracted with Et_2O. The organic phase was dried over $MgSO_4$ and concentrated to give the crude compound. The crude material was purified by column chromatography (light petroleum–Et_2O) over silica gel to give the pure product.

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(22) **General Procedure for Amide Formation**: Amine (1 mmol) was dissolved in anhyd toluene (2 mL), and sesquihalide (0.67 mmol) prepared by method 2 was added. The reaction mixture was stirred at r.t. for 10 min. The ester (0.5 mmol) was added to the reaction mixture and the mixture was heated to 80 °C for 3 h. The reaction was quenched with HCl (2 M) and extracted with Et_2O. The organic phase was dried over $MgSO_4$ and concentrated to give the crude compound. The crude material was purified by column chromatography (light petroleum–Et_2O) over silica gel to give the pure product.