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Generation of a Reducing Reagent from Copper(I) Salt and Hydrosilane. New Practical Method for Conjugate Reduction[1]

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Abstract: Hydride transfer from a hydrosilane to a copper(I) salt is reported. The silicon group of hydrosilanes was smoothly replaced by copper(I) chloride in DMI to give the corresponding metal hydride complex of copper(I). This transformation was applied to conjugate reduction of α,β-unsaturated compounds with a hydrosilane mediated by copper(I) chloride. © 1997 Elsevier Science Ltd.

Metal hydride complexes of copper have been utilized for the stereoselective and chemoselective conjugate reduction of α,β-unsaturated carbonyl compounds.[2] These copper hydride reagents were usually prepared by the reaction of a reactive metal hydride species with a copper(I) salt. Highly reactive hydride reagents such as lithium aluminum hydride, diisobutylaluminum hydride and tributyltin hydride were employed in the preparation of complexes of copper(I) hydride.[3] However, there have been no reports that hydrosilane was used as a hydride source of copper(I) hydride.[4] We report herein a new, convenient procedure for the stereo- and chemoselective conjugate reduction of α,β-unsaturated carbonyl compounds by use of a complex of copper(I) hydride generated from a hydrosilane and a copper(I) salt in a polar solvent.

Recently, we reported that the organic group transfer from organosilicon compounds to a copper(I) salt occurred in an aprotic polar solvent such as DMI (1,3-dimethylimidazolidinone).[5,6] Under these conditions, alkynyl-, aryl- and heteroarylsilanes were smoothly converted to the corresponding organocopper reagents. Then, we tested hydride transfer from hydrosilane to copper(I) salt in DMI. Addition of dimethylphenylsilane **1a** (68 mg, 0.5 mmol) to a suspension of dry copper(I) chloride (50 mg, 0.5 mmol) in DMI (0.5 mL) at room temperature under nitrogen resulted in a black-red solution along with the consumption of the hydrosilane. After stirring for 2 h, the starting hydrosilane **1a** disappeared and the formation of chlorosilane **2a** was observed by glc (eq. 1). In order to characterize the product of the reaction, ^{29}Si NMR measurement of the resultant black-red mixture was carried out under nitrogen. The spectra showed a single broad peak at δ 21.0 which was identical with the corresponding chlorosilane **2a**.[7] The chlorosilane **2a** observed in the mixture would be a counterpart of the products of silicon-copper exchange reaction of hydrosilane and copper(I) chloride. These results suggest that the hydride transfer reaction from hydrosilane **1a** to copper(I) salt also occurs under the same conditions, previously reported. However, attempts to characterize the hydride proton on copper(I) with ^{1}H NMR were unsuccessful.

$$\underset{\mathbf{1a}}{\mathrm{PhMe_2SiH}} + \mathrm{CuCl} \xrightarrow[\text{DMI, r.t. 2 h}]{} \underset{\mathbf{2a}}{\mathrm{PhMe_2SiCl}} + \text{"}\mathit{Cu-H}\text{"} \qquad (1)$$

We examined a combination of various solvents, copper(I) salts and hydrosilanes in order to optimize this transformation in detail (eq. 2). The results are shown in Table 1. The solvent plays an important role in this reaction (entries 1-5). Only in DMI and DMF (*N,N*-dimethylformamide) the consumption of the hydrosilane was observed. Use of CuI or CuCN instead of CuCl decreased conversion of the hydrosilane (entries 6,7). Diphenylsilane **1b** is also a good substrate (entry 8). Reaction rate of triethylsilane **1c** with CuCl were relatively slower than dimethylphenylsilane **1a** (entry 9).

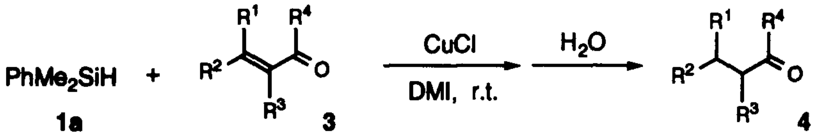
Table 1. Reactions of hydrosilane **1** with copper(I) salt[a]

$$\underset{\mathbf{1}}{R^1R^2R^3SiH} + CuX \xrightarrow[\text{Solvent}]{} \underset{\mathbf{2}}{R^1R^2R^3SiX} + \text{"}\mathit{Cu-H}\text{"} \qquad (2)$$

Entry	Hydrosilane 1	Copper salt	Solvent	Conversion of 1 / %[b]
1	$PhMe_2SiH$ **1a**	CuCl	DMI	92
2	**1a**	CuCl	DMF	99
3	**1a**	CuCl	CH_3CN	0
4	**1a**	CuCl	THF	0
5	**1a**	CuCl	CH_2Cl_2	0
6	**1a**	CuI	DMI	21
7	**1a**	CuCN	DMI	0
8	Ph_2SiH_2 **1b**	CuCl	DMI	99
9	Et_3SiH **1c**	CuCl	DMI	86

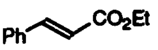
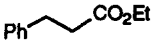
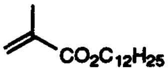
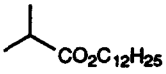
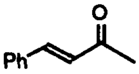
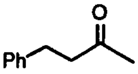
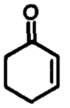
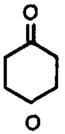
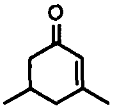
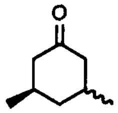
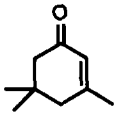
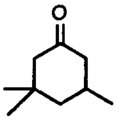
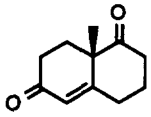
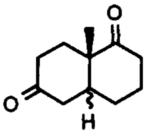
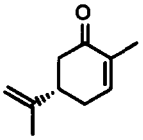
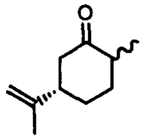
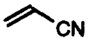
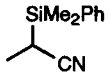
[a] A mixture of a copper (I) salt (0.5 mmol) and a hydrosilane (0.5 mmol) was stirred at room temperature for 1 h in a solvent (0.5 mL). [b] Conversion was deteremined by GLC.

In the presence of a Michael acceptor, a mixture of a hydrosilane and a copper salt in DMI was used as a practical reducing reagent (eq. 3). Conjugate reduction of α,β-unsaturated carbonyl compounds with **1** proceeded smoothly in the presence of a catalytic or stoichiometric amount of CuCl. In most cases, a combination of dimethylphenylsilane **1a**, CuCl and DMI gave good results. Representative results are listed in Table 2. A typical procedure is given as follows. To a mixture of ethyl cinnamate **3a** (176 mg, 1.0 mmol) and CuCl (99 mg, 1.0 mmol) in DMI (1.0 mL) dimethylphenylsilane 1a (272.5 mg, 2.0 mmol) was added at room temperature. After stirring for 5 h at room temperature, the reaction mixture was diluted with hexane. Filtration through a short-column chromatography (Frolisil®, ethyl acetate : hexane = 1 : 10) followed by purification using column chromatography (SiO_2, ethyl acetate : hexane = 1 : 20) gave ethyl 3-phenylpropionate **4a** (171 mg, 96% yield). A catalytic amount of copper(I) chloride (0.2-0.5 equiv.) can be applied in this reaction and gave the reduced product in a slight decreased yield. However, under the conditions of a smaller equivalent of copper(I) chloride (less than 0.1 equiv.) the yield dropped (entry 4). Thus, in most cases of this conjugate reduction, use of a stoichiometric or excess amount of copper chloride and the hydrosilane resulted in good yields. Under this condition, both acyclic and cyclic α,β-unsaturated ketones also converted to the corresponding saturated products in excellent yield without the 1,2-reduction (entries 6-11). Reactions of **3e** and **3g** were quite stereoselective and gave mainly *cis* products (entries 8, 10). The observed selectivity in the reduction of **3g** is superior to the catalytic hydrogenation and the reduction using Stryker's copper(I) hydride complex $[(Ph_3P)CuH]_6$.[3d,8]



(3)

Table 2. Conjugate reduction of α,β-unsaturated compounds **3** by the hydrosilane **1a** catalyzed by copper(I) chloride[a]

Entry	α,β-Unsaturated compounds 3		Hydrosilane 1a / equiv.	CuCl / equiv.	Time / h	Product 4		Yield of 4 / %[b]
1		**3a**	2	1	5		**4a**	96
2	**3a**		2	0.5	5	**4a**		90
3	**3a**		2	0.2	5	**4a**		86
4	**3a**		2	0.1	5	**4a**		0
5		**3b**	4	2	6		**4b**	95
6		**3c**	4	2	5		**4c**	92[c]
7		**3d**	4	2	22		**4d**	quant[d]
8		**3e**	4	2	22		**4e**	quant[d,e] (97 : 3)
9		**3f**	4	2	20		**4f**	13
10		**3g**	4	2	21		**4g**	81[e] (98 : 2)
11		**3h**	4	2	22		**4h**	83
12		**3i**	4	2	14		**4i**	92

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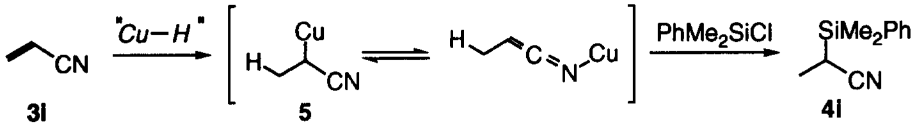
[a] A mixture of a hydrosilane, an α,β-unsaturated compound (0.5 mmol) and CuCl was stirred in DMI (0.5 mL) at room temperature. [b] Isolated yield unless otherwise noted. [c] DMI (2.0ml) was used. [d] Yield was determined by GLC analysis. [e] The isomer ratio (*cis* : *trans*) was determined using capillary GLC and shown in the parenthesis.

An unsuccessful result with 3,5,5-trimethylcyclohexenone **3f** indicated that the reactivity of this reducing agent is sensitive to steric hindrance of the substrate (entry 9). Both isolated carbonyl group and olefinic double bond were not reduced under these conditions (entries 10, 11). In a case of an unsaturated nitrile **3i**, an α-silylated product was obtained in good yield (entry 12). In this case, the 1,4-addition of copper(I) hydride to acrylonitrile **3i** first took place. Next, the resultant organocopper species **5** reacted with chlorosilane that was formed by copper-silicon exchange reaction successively (eq. 4). In this reaction only the α-silylated product was observed, in contrast to the exclusive β-silylation of acrylates catalyzed by a combination of copper and tetramethylethylenediamine.[9]



(4)

In conclusion, the direct silicon-copper exchange reaction occurred easily in DMI in the absence of the fluoride ion. These results provide not only valuable insight into organosilicon chemistry but also a practical method for the conjugate reduction of α,β-unsaturated carbonyl compounds under mild conditions. Further characterization of the reaction mechanism and the structure of reductive species is under active investigation.

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