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**Direct synthesis of alkylsilanes by platinum-catalyzed coupling of
hydrosilanes and iodoalkanes**

A direct and versatile method that employs a Pt-catalyzed system has been developed for the alkylation of Si–H bonds. With this approach, iodoalkanes and tertiary silanes were successfully coupled with good functional group tolerance. The utility of this methodology is demonstrated by the synthesis of silafluofen, a Si-containing insecticide.

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Direct synthesis of alkylsilanes by platinum-catalyzed coupling of hydrosilanes and iodoalkanes†

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Alkyl iodides and tertiary silanes were successfully coupled with good functional group tolerance using a Pt(P(*t*Bu)₃)₂/(*i*Pr)₂EtN/CH₃CN system. The utility of the methodology is demonstrated by the synthesis of silafluofen, a Si-containing insecticide.

Alkylsilanes are of great interest in medicinal chemistry owing to their various biological activities.¹ For example, alkylsilanes have recently been employed as insecticidal protectants,² anticancer agents,³ and muscle relaxants.⁴ As a consequence, significant research effort is currently being directed toward the development of reproducible and high-yielding preparative procedures for this interesting class of compounds. To date, the common approaches for the preparation of alkylsilanes make use of the Rochow process, chlorosilanes with organometallic reagents, and hydrosilylation of olefins,⁵ the synthetic utility of which is limited.

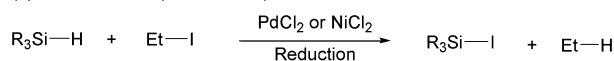
Hydrosilanes have been widely used as mild reducing agents in organic synthesis. In general, hydrosilanes do not react spontaneously with carbon electrophiles; however, the use of certain transition metal catalysts can enable fine control of the reduction process. Reactions of hydrosilanes with alkyl halides in the presence of suitable transition metal catalysts have been previously shown to proceed with the liberation of alkanes and halogenated silanes. For example, Kunai *et al.*, Chatgililoglu *et al.*, and Srithanakit and Chavasiri independently reported the syntheses of mono- and diiodosilanes in high yield (Scheme 1(a)) from reactions of hydrosilanes with alkyl iodides in the presence of PdCl₂ or NiCl₂, respectively.⁶ Miura *et al.* also reported alkyl radical mediated indium-catalyzed reduction of alkyl halides to their corresponding alkanes with hydrosilanes in high yield.⁷

Throughout the course of our studies on the synthetic use of hydrosilanes, we have demonstrated a number of examples of transition metal-catalyzed arylation of hydrosilanes.^{8–10} However, our method was limited in that it could only be applied to aryl iodides. In fact, silylation of iodoalkanes has yet to be shown.

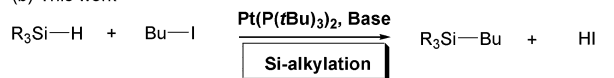
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† Electronic supplementary information (ESI) available: Compound characterization data and copies of ¹H and ¹³C NMR. See DOI: 10.1039/c2cc35150a

(a) Previous work (Reference 6)



(b) This work

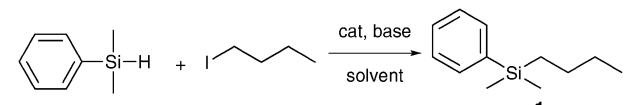


Scheme 1 Metal-catalyzed reactions of hydrosilanes and iodoalkanes.

Therefore, we herein report a remarkably convenient and efficient method for the synthesis of alkylsilanes (Scheme 1(b)) which proceeds *via* platinum-catalyzed alkylation of hydrosilanes with iodoalkanes.

The model studies of our catalytic system were carried out using dimethylphenylsilane and 1-iodobutane (Table 1). Various palladium and platinum complexes were selected as the alkylating catalysts because both Si–H^{11,8a,d,f-h} and alkyl–I¹² bond activation have been demonstrated for each metal. Contrary to our expectations, the palladium complexes employed did not show any catalytic activity even under the same conditions previously developed for the arylation of hydrosilanes (entries 1 and 2). On the other hand, the selected platinum complexes successfully catalyzed the desired alkylation, which is the first example of catalytic alkylation of hydrosilanes. Successful results were first obtained with Pt(PPh₃)₂(CH₂=CH₂) employed as catalyst (entry 4).¹³ Among the platinum catalysts considered, Pt(P(*t*Bu)₃)₂ exhibited the best performance (55% yield, entry 5). An investigation into the solvent effects on the reaction system of interest revealed that the alkylation notably proceeded in polar and coordinating solvents such as ethers or nitriles, with acetonitrile being the most favorable (entry 11). Following a brief screening of bases, (*i*Pr)₂EtN was found to provide the shortest reaction time and the highest yield (60%) (entry 11). Although iodoalkanes were the most efficient substrates, the corresponding bromoalkanes could also be employed with this system, albeit with the desired products being obtained in reduced yields.¹⁴

Fig. 1 summarizes the scope of the alkylation reaction using various hydrosilanes and iodoalkanes under the optimized reaction conditions. The cross-coupling proceeds smoothly over

Table 1 Screening of reaction conditions^a


Entry	Catalyst	Base	Solvent	Time (d)	Yield (%)
1	Pd(PPh ₃) ₄	(iPr) ₂ EtN	THF	3	— ^b
2	Pd(P(<i>t</i> Bu) ₃) ₂	(iPr) ₂ EtN	THF	3	— ^b
3	Pt(PPh ₃) ₄	(iPr) ₂ EtN	THF	3	— ^b
4	Pt(PPh ₃) ₂ (CH ₂ =CH ₂)	(iPr) ₂ EtN	THF	3	19
5	Pt(P(<i>t</i> Bu) ₃) ₂	(iPr) ₂ EtN	THF	2	55
6	Pt(P(<i>t</i> Bu) ₃) ₂	(iPr) ₂ EtN	1,4-Dioxane	1	41
7	Pt(P(<i>t</i> Bu) ₃) ₂	(iPr) ₂ EtN	CH ₂ Cl ₂	1	<1
8	Pt(P(<i>t</i> Bu) ₃) ₂	(iPr) ₂ EtN	CH ₃ NO ₂	3	<1
9	Pt(P(<i>t</i> Bu) ₃) ₂	(iPr) ₂ EtN	Toluene	1	<1
10	Pt(P(<i>t</i> Bu) ₃) ₂	(iPr) ₂ EtN	PhCN	3	34
11	Pt(P(<i>t</i> Bu) ₃) ₂	(iPr) ₂ EtN	CH ₃ CN	1	60
12	Pt(P(<i>t</i> Bu) ₃) ₂	Et ₃ N	CH ₃ CN	3	46
13	Pt(P(<i>t</i> Bu) ₃) ₂	Cy ₂ MeN	CH ₃ CN	3	47
14	Pt(P(<i>t</i> Bu) ₃) ₂	K ₃ PO ₄	CH ₃ CN	3	28

^a Reaction conditions: all reactions consisted of 1-iodobutane (1.0 mmol), dimethylphenylsilane (3.0 mmol), base (1.0 mmol), catalyst (0.05 mmol) in 2 mL of solvent and were performed under Ar at 50 °C. ^b Not detected.

a wide range of substrates in moderate to good yield. Firstly, we considered the reactivity of a variety of hydrosilanes in a model reaction (1). Interestingly, ethylmethylphenylsilane could be alkylated by this reaction (2). Hydrosilanes with two or three phenyl groups displayed opposite results. Methylphenylsilane (3) gave almost the same yield as that of the model reaction, whereas triphenylsilane was unreactive owing to significant steric effects. Phenyl ring substituents at the 4-position of phenyldimethylsilane had little effect on the silane reactivity (4 and 5). Notably, 2-phenyldimethylsilane could be readily alkylated by the presented method (6).

The generality of this alkylation reaction was explored by employing different iodoalkanes. The reaction proceeded smoothly with other considered 1-iodoalkanes (7 and 8). Interestingly, iodomethane was also a suitable substrate for this alkylation process (9). Similarly, 1,3-diiodopropane could couple twice with two equivalents of hydrosilane in low yield (10). The introduction of a trifluoromethyl substituent at the terminus of an iodoalkane had no significant influence on reactivity (11). In addition, 1-iodoalkanes with reactive functional groups, such as an ester and a nitrile, which frequently require protection in conventional methods that make use of organometallic reagents, were well tolerated in this reaction system (12 and 13). Furthermore, the reaction of 1-chloro-3-iodopropane (14) indicated that this catalytic system exhibited halogen-selectivity. The catalytic system also proved to be effective in the case of trialkylsilane (15). In all reactions considered, reduced compounds (alkanes) were obtained in *ca.* 10–50% as side products. As compared to primary alkyl iodides, secondary or tertiary alkyl iodides were much less reactive. For example, the reaction of phenyldimethylsilane and 2-iodobutane under optimized conditions afforded only a trace amount of the expected alkylated silane product.

To highlight the practical utility of the developed catalytic system, it was employed in a simplified synthesis of the insecticide silafluofen, 16.^{2b-d} Silafluofen has been used as an agricultural insecticide since 1995 in Japan owing to its high insecticidal activity, low toxicity, and chemical stability under various environmental conditions. Under the optimum reaction conditions described above, dimethyl(4-ethoxyphenyl)silane was successfully coupled with 1-iodo-3-(4-fluoro-3-phenoxyphenyl)propane¹⁵ to afford silafluofen 16 in 42% yield. Because the market for household insecticides is estimated to be about 100 billion yen per year, this new alkylation reaction is promising from a practical

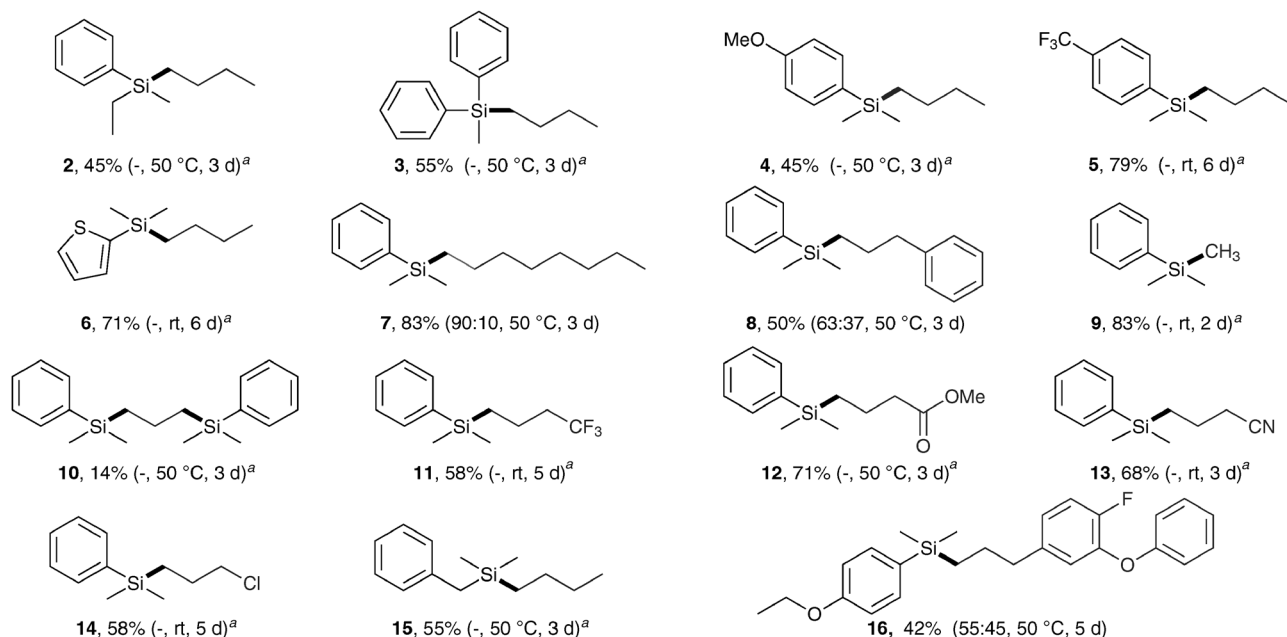


Fig. 1 Substrate scope of the Pt-catalyzed alkylation of tertiary silanes. Yields are isolated yields. Numbers in parentheses represent the ratio of alkylsilane : alkane, reaction temperature, and reaction time. The ratios were determined by GC-MS of crude reaction mixture. ^a The ratios could not be determined due to high volatility of reduced alkanes.

standpoint as it enabled the straightforward preparation of an organosilane insecticide bearing a pyrethroid structure.

Although the mechanistic details of the demonstrated catalysis are not presently clear, NMR experiments have been carried out to verify the operative catalytic pathways. The components of the initial step were elucidated by carefully monitoring the ^1H NMR of the reaction between dimethylphenylsilane and iodomethane, which revealed that $\text{Pt}(\text{tBu})_3$ initially dissociates from $\text{Pt}(\text{P}(\text{tBu})_3)_2$ in the presence of iodomethane to afford $((\text{tBu})_3\text{PCH}_3)^+\text{I}^-$ and $\text{PtP}(\text{tBu})_3$. The doublet peaks observed in the reaction ^1H NMR ($((\text{tBu})_3\text{PCH}_3)^+\text{I}^-$: δ 1.74 (d, J = 12.0 Hz), 1.55 (d, J = 14.5 Hz); $\text{PtP}(\text{tBu})_3$: δ 1.50 (d, J = 13.0 Hz)) are characteristic of $((\text{tBu})_3\text{PCH}_3)^+\text{I}^-$ and $\text{PtP}(\text{tBu})_3$.^{16,17} The aforementioned potentially explains why $\text{Pt}(\text{P}(\text{tBu})_3)_2$ could not successfully catalyze the reactions of much bulkier secondary or tertiary iodoalkanes. Here, $\text{PtP}(\text{tBu})_3$, which is a highly reactive species, is most likely coordinated by acetonitrile and thus, present in solution as the more stable complex, $\text{PtP}(\text{tBu})_3(\text{CD}_3\text{CN})_n$ (n = 0–2). This notion is supported by the fact that the reaction proceeds more readily in coordinating solvents (Table 1). ^1H NMR of the reaction did not contain any signals derived from Pt–H or Pt–CH₃ during the course of the synthesis and therefore, it was not possible to determine which species, hydrosilane or iodomethane, underwent oxidative addition first.

On the basis of the above results, we propose a plausible mechanism as shown in Fig. S2 (ESI[†]) for the Pt-catalyzed alkylation of tertiary silanes. Initially, dissociation of one $\text{P}(\text{tBu})_3$ molecule from $\text{Pt}(\text{P}(\text{tBu})_3)_2$ occurs smoothly in the presence of the alkyl iodide. Coordination of CH_3CN stabilizes the formed active intermediate, $\text{PtP}(\text{tBu})_3$, to which oxidative addition occurred.^{11,12c} Followed by additional oxidative addition¹⁸ or σ -bond metathesis,¹⁹ reductive elimination affords the desired alkylsilane in the presence of base with concomitant regeneration of $\text{PtP}(\text{tBu})_3$.

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