Formation of transition metal carbenes using haloalkylzinc reagents

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A new reaction of haloalkylzinc compounds, leading to transition metal carbenes, is described; halomethylzinc and halobenzylzinc compounds react with ruthenium and iridium complexes to form methylene and benzylidene complexes, including the Grubbs catalyst.

Haloalkylzinc reagents are useful reagents in organic synthesis. For example, bis(iodomethyl)zinc and diiodomethylzinc iodide, produced in situ from diiodomethane and diethylzinc, are used in the Simmons-Smith cyclopropanation reaction, which has been a subject of intensive investigations over the past five decades. They are also used in homologation and alkylation. Haloalkylzinc compounds, stabilized by coordination of bipyridine, were isolated.

We were intrigued by the possibility of employing haloalkylzinc compounds as reagents for the formation of transition metal Schrock-type carbene (alkylidene) complexes, which are widely used in synthetic chemistry. For instance, catalysis of alkene metathesis reactions by Schrock molybdenum alkylidene and Grubbs ruthenium alkylidenes has resulted in a multitude of synthetic applications.

Several useful methods for the synthesis of alkylidene complexes have been described, perhaps the most common one being based on diazoalkane precursors. However, this method suffers from thermal instability of the diazo precursors and in many cases, metal diazo adducts are formed rather than carbene complexes. Recently, we have developed a general method for the preparation of carbene complexes based on the use of sulfur ylides, which are prepared in situ from simple sulfonium salts.

We have now discovered a new reaction, involving haloalkyl zinc compounds, which upon reaction with transition metal complexes lead to metal alkylidenes. Using halomethylzinc and halobenzylzinc reagents, Grubbs-type ruthenium methylidene and benzylidene complexes and an Ir-based benzylidene complex were formed.

First, we have examined the reaction of the common cyclopropanation reagent, bis(iodomethyl)zinc, with Ru(II). A slightly modified literature procedure was used for the in situ formation of this reagent. Addition of a hexane solution of Et₂Zn (2 equivalents) to a dichloromethane solution of CH₂Cl₂ (4.4 equivalents) at −30 °C followed by warming to 0 °C resulted in formation of the iodomethylzinc complex 1 (Scheme 1). To this reaction mixture was added a methylene chloride solution of (PPh₃)₃RuCl₂ 2 (one equivalent) at −30 °C, followed by substitution of the triphenylphosphine ligands by tricyclohexylphosphine (2.5 equivalents), for stabilization of the resulting carbene complex. After 2 h at room temperature, ³¹P and ¹H NMR spectra revealed formation of the previously reported complex (PCy₃)₂Cl₂Ru-CH₂ (3) in 80% yield. The synthesis of this compound by the sulfur ylide method resulted in a low yield, due to the instability of the methylene sulfur ylide. To our knowledge, this is the first example of the use of haloalkyl zinc reagents (or, to our knowledge, metal carbenoid precursors in general) for the preparation of a metal alkylidene complex.

Studying the applicability of the reaction for the formation of alkylidene complexes beyond methylidene, we applied it to formation of the widely used Grubbs ruthenium benzylidene catalyst. Indeed, the reaction proceeded smoothly with the benzal chloride-derived zinc reagent. Thus, addition of Et₂Zn to a methylene chloride solution of benzal chloride at −30 °C led to formation of a yellow precipitate, presumably the bis(chlorobenzyl)zinc complex 4, which was reacted in situ with (PPh₃)₃RuCl₂.

Following substitution of the triphenylphosphine ligands by tricyclohexylphosphine, complex (PCy₃)₂RuCl₂(=CCHPh) 5 was formed in 81% yield, as indicated by ³¹P NMR. Following workup, this complex was isolated in 63% yield (Scheme 2).

The reaction of haloalkyl zinc reagents with transition metal complexes is not limited to ruthenium complexes. For instance, this reaction can be utilized for formation of an iridium benzylidene complex. While dissubstituted alkylidene iridium complexes, trans-[(PR₃)₂IrCl(=CPh)] were synthesized, and iridium methylene complexes were also reported, stable mono-substituted alkylidene iridium complexes were unknown until, recently, trans-[(PPr₃)₂ClIr(=CPh)] 7 was prepared by utilizing the sulfur ylide-based method. We have now found that the iridium reagent based reaction is also capable of direct formation of complex 7. Thus, when the chlorobenzyl zinc reagent, generated in situ from Et₂Zn and benzal chloride, was reacted with the in situ prepared [(PPr₃)₃IrCl]₂ complex 6 at −30 °C, complex 7 was formed in 60% isolated yield (Scheme 2).

Scheme 1

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Theoretical studies showed that haloalkyl zinc reagents undergo the cyclopropanation reaction through a methylene transfer mechanism, in which the metal center of the transition metal complex behaves as a nucleophile and attacks the methylene (or benzylidene) group, with concomitant transfer of the halide to zinc, resulting in formation of ZnX2 and the carbene complex (Scheme 3).

To summarize, a new reaction, involving haloorganozinc carbenoid donors and transition metal complexes, leading to alkylidene complexes, has been discovered. While the scope of this reaction has not been fully explored yet, we have already observed that this facile and synthetically simple reaction can be utilized for formation of methylene and benzylidene complexes of ruthenium and iridium, including the Grubbs catalyst.

Notes and references

† Synthesis of \((\text{PCy}_3)_2\text{RuCl}_2\cdot\text{CHPh}\) 5.

A pre-cooled to \(-30^\circ\text{C}\) methylene chloride solution (3 ml) of benzylic chloride (20 µl, 0.157 mmol) was treated with a \(-30^\circ\text{C}\) 1 M hexane solution of Et2Zn (91 µl, 0.091 mmol). After 30 min, the solution was warmed to 0°C and stirred until a yellow–brown precipitate of the complex 4 appeared. Then 1.5 ml of a cold dichloromethane solution of \((\text{PPPh}_3)_2\text{RuCl}_2\) (35 mg, 0.037 mmol) were added. After 1 h at \(-30^\circ\text{C}\), cold \(\text{PCy}_3\) (25 mg, 0.091 mmol) in 1 ml of \(\text{CH}_2\text{Cl}_2\) was added and the reaction was warmed to room temperature and stirred for 1 h. The solvent was evaporated, the purple solid was washed with methanol (3 \times 5 ml) and dried under vacuum to give 19 mg (0.023 mmol, 63% yield) of complex 5, \((\text{PCy}_3)_2\text{RuCl}(\text{CHPh})\).\(^{15}\) Spectral data were identical to those reported in the literature.

Synthesis of \((\text{PCy}_3)_2\text{Cl}_2\text{Ru}^+=\text{CHPh}\) 3.

To a methylene chloride (1.5 ml) solution of methylene iodoide (11 µl, 0.137 mmol) at \(-30^\circ\text{C}\) was added a 1 M solution of Et2Zn in hexane (62 µl, 0.062 mmol) pre-cooled to \(-30^\circ\text{C}\). After 15 min at \(-30^\circ\text{C}\), the reaction vessel was warmed to 0°C and a white precipitate of iodomethylidene complex 1 appeared. The mixture was cooled again to \(-30^\circ\text{C}\) and 1.5 ml of a cold dichloromethane solution of \((\text{PPPh}_3)_2\text{RuCl}_2\) (30 mg, 0.031 mmol) was added. After 30 min at \(-30^\circ\text{C}\), \(\text{PCy}_3\) (21 mg, 0.078 mmol) in 1 ml of \(\text{CH}_2\text{Cl}_2\) was added and the reaction was kept for an additional 10 min at \(-30^\circ\text{C}\) followed by warming up to room temperature. After 2 h, \(^{31}\text{P}\) and \(^1\text{H}\) NMR spectra revealed formation of the known \(^{13}\) complex \((\text{PCy}_3)_2\text{Cl}_2\text{Ru}^+=\text{CH}_2\) 3 in 80% yield. Due to the instability of complex 3, its isolation in pure form was not possible, and the yield was determined by \(^{31}\text{P}\) NMR using triphenylphosphine oxide as an internal standard. Spectral data were identical to those reported in the literature.

Synthesis of \((\text{PPPh}_3)_2\text{Cl}^+=\text{CHPh}\) 7.

To a pentane (7 ml) suspension of \([\text{COE})_2\text{IrCl}]_2\) (82 mg, 0.091 mmol) then its volume was reduced to 2 ml. Prepared in situ as described in preparation of 5 (benzyl chloride 52 µl, 0.405 mmol and Et2Zn 235 µl, 0.235 mmol), chlorobenzylzinc complex 4 in 2 ml of \(\text{CH}_2\text{Cl}_2\) was treated with a solution of 6 pre-cooled to \(-30^\circ\text{C}\). After 30 min at \(-30^\circ\text{C}\), 5 ml of \(\text{CH}_2\text{Cl}_2\) was treated with pentane and the product complex 7 was extracted with toluene. Removal of solvent by vacuum, gave 69 mg (0.109 mmol, 60% yield) of the known \(^{13}\) complex 7. Spectral data were identical to those reported in the literature.


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