Ceric(IV) Ammonium Nitrate: A Novel Reagent for the Synthesis of Homoallyl Alcohols

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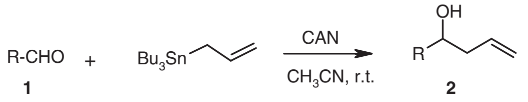
A rapid and highly efficient method has been developed for the allylation of aldehydes with allyltributylstannane using a catalytic amount of ceric ammonium nitrate in acetonitrile under mild and neutral conditions to afford the corresponding homoallyl alcohols in excellent yields with high chemoselectivity. Allylation of ketones has also been achieved with tetraallytin under similar reaction conditions.

The stereoselective addition of allylmetal reagents to aldehydes is one of the most important carbon–carbon bond forming reactions in organic synthesis.[1] Several methods have been developed for the allylation of aldehydes with allyl metals to produce homoallylic alcohols.[2] One of the most straightforward synthetic procedures for the synthesis of homoallylic alcohols involves the addition of allyltin reagents to aldehydes in the presence of acid catalysts.[3,4] Recently, metal triflates are also found to be effective for this transformation.[5] However, the development of a neutral alternatives such as ceric ammonium nitrate would extend the scope and generality of these allylation reactions. Ceric ammonium nitrate has emerged as powerful single electron transfer reagent in many carbon–carbon bond-forming reactions.[6]

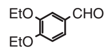
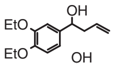
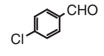
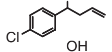
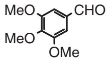
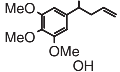
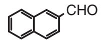
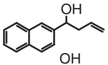
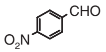
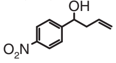
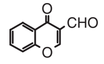
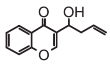
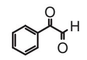
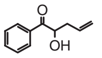
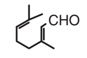
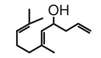
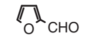
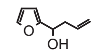
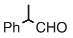
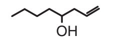
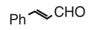
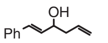
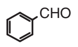
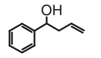
Herein, we wish to report that ceric ammonium nitrate (CAN) is a mild and highly efficient catalyst for the allylation of aldehydes with allylstannane under neutral conditions (Scheme 1).

The treatment of benzaldehyde with allylstannane in the presence of 5 mol% CAN in acetonitrile afforded 1-phenyl-3-buten-1-ol in 95% yield. Similarly, various aliphatic, aromatic, heterocyclic and α,β-unsaturated aldehydes were converted to the corresponding homoallylic alcohols in excellent yields by using this procedure. In all cases, the reactions proceeded efficiently at ambient temperature with high chemoselectivity. No bis-allylated products are obtained with methoxy-substituted aryl aldehydes, which are normally observed in the allylation reactions of methoxybenzaldehydes with allyltrimethylsilane.[7] Acid sensitive aldehydes such as furfural, 2-phenylacetaldehyde and cinnamaldehyde were also smoothly reacted with allyltin to afford the corresponding homoallylic alcohols in excellent yields. In case of 2-phenylpropanal, the product was obtained as a diastereomeric mixture of *syn* and *anti* in 3:1 ratio (entry j, Table 1).[8] However, the treatment of ketones such as acetophenone, tetralone, 1,4-cyclohexanedione, 4-phenylcyclohexanone and β-ketoesters did not react with allyltributylstannane by ceric ammonium nitrate even after a long reaction time and thus this provides chemoselective allylations of aldehydes without affecting keto functionality. The chemoselectivity of the present method was further studied by using the keto aldehydes (entries f, g).



Scheme 1.

Table 1. Cerium(IV)-catalyzed allylation of aldehydes with allyltributylstannane

Entry	Aldehyde	Homoallyl alcohol[a]	Time /min	Yield /%[b]
a.			20	92
b.			30	95
c.			25	90
d.			20	92
e.			45	87
f.			35	89
g.			30	90
h.			35	91
i.			20	92
j.			30	95[c]
k.			25	90
l.			35	92
m.			30	95

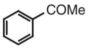
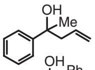
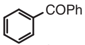
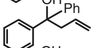
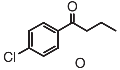
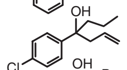
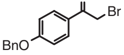
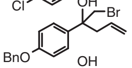
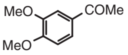
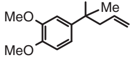
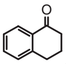
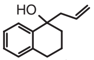
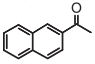
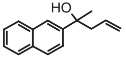
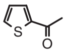
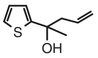
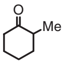
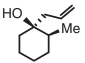
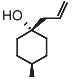
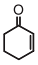
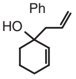
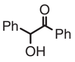
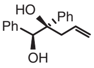
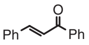
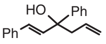
[a]All the products were characterized by ^{1}H NMR, IR and mass spectroscopy[b]Isolated and unoptimized yields. [c] The product was obtained as a mixture of *syn*:*anti* in a ratio of 3:1.

The allylation reactions of various aldehydes with allyltributylstannane have been studied and the results are presented in Table 1. Interestingly, ketones reacted smoothly and rapidly with tetraallytin in the presence of ceric ammonium nitrate to afford the corresponding homoallylic alcohols in excellent yields (Scheme 2).

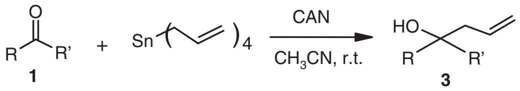
In all cases, the reactions proceeded rapidly at ambient temperature with high chemoselectivity. A variety of ketones such as aryl, alkyl, cyclic, α,β-unsaturated, heterocyclic and α-hydroxy ketones were converted into their corresponding homoallylic alcohols in high yields by using this procedure and the results are presented in the Table 2.

In case of 2-methylcyclohexanone, the product was obtained as *cis*-adduct (entry i, Table 2) whereas 4-phenylcyclohexanone gave *trans*-cyclohexanol (entry j, Table 2). Similarly, benzoin afforded the corresponding homoallyl alcohol as *syn*-adduct (entry l, Table 2). These results are similar to those obtained with

Table 2. Cerium(IV)-catalyzed allylation of ketones with tetraallyltin

Entry	Ketone	Homoallyl alcohol[a]	Time/h	Yield/%[b]
a.			1.0	95
b.			2.5	89
c.			2.0	93
d.			2.5	88
e.			2.0	90
f.			1.5	87
g.			1.0	92
h.			2.5	90
i.			3.5	89[c]
j.			3.0	91[d]
k.			3.0	85
l.			3.5	87[e]
m.			4.0	70

[a]All the products were characterized by ^1H NMR, IR and mass spectroscopy.[b]Isolated and unoptimized yields [c] 2-Methylcyclohexanone gave only *cis*-adduct. [d]*trans*-Cyclohexanol derivative was obtained with 95% de.[e]*syn*-Adduct was obtained with 99% de.



Scheme 2.

other methods.[9] Although, aldehydes reacted smoothly with tetraallyltin even in the absence of catalyst, ketones did not yield any product even after a long reaction time. The allylation of ketones was successful only with tetraallyltin and ceric ammonium nitrate. Among various Lewis acids such as $CeCl_3.7H_2O$, $Ce(OTf)_3$, $YbCl_3$, $SmCl_3$ and YCl_3 studied for this transformation, cerium(IV) ammonium nitrate was found to be more effective than others in terms of conversion and reaction times. For example, the treatment of benzaldehyde with allyltributylstannane in the presence of 5 mol% CAN and 5 mol% $Ce(OTf)_3$ gave 95%, and 75% yields respectively over 30 min. However, the stoichiometric amounts of $CeCl_3.7H_2O$ and NaI were required to obtain comparable yields to those obtained with catalytic amount of CAN. Furthermore, the reactions did not proceed in the presence of NH_3 or NH_4Cl or $NaNO_2$ and/or tetrabutyl ammonium nitrate in acetonitrile at room temperature. This clearly indicates the catalytic role of CAN in this conversion.[10]

In summary, this paper describes a rapid and highly efficient protocol for the allylation of carbonyl compounds with allyltin reagents using a cheap and readily available reagent, cerium ammonium nitrate under mild and neutral conditions. This method offers significant advantages such as very short reaction times, improved yields, cleaner reaction profiles, operational simplicity and high chemoselectivity, which makes it a useful process for the synthesis of homoallyl alcohols.

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10 *Experimental procedure*: A mixture of aldehyde (2 mmol), allyltributylstannane (2 mmol) or [1 mmol of tetraallyltin for the allylation of 2 mmol of ketone] and ceric ammonium nitrate (5 mol%) in acetonitrile (1 mL) was stirred at ambient temperature for an appropriate time (Tables 1, 2). After completion of the reaction, as indicated by TLC, the reaction mixture was diluted with water (20 mL) and extracted with ethyl acetate (2 × 15 mL). The combined organic layers were washed with brine, dried over anhydrous Na_2SO_4 and concentrated in vacuo, and the resulting product was purified by column chromatography on silica gel (Merck, 100–200 mesh, ethyl acetate-hexane, 2:8) to afford pure homoallyl alcohol.