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A New Direct Allylation of the Aromatic Compounds with Allylic Chlorides Catalyzed by Indium Metal

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Abstract

A new method of the direct allylation reaction for the aromatic compounds with allylic chlorides using a catalytic amount of indium in the presence of $CaCO_3$/4 Å molecular sieves was developed.

Key words: allylation ; catalyst ; Friedel-Crafts reaction ; indium and compounds

Direct allylation of the aromatic compounds using allyl chloride catalyzed by a Lewis acid such as $AlCl_3$ has been known undesirable to give a complex mixture of products[1]. Although various alternative methods for allylation of the aromatic nucleus using allyl chloride, allyl alcohol or the allylmetal compounds have been exploited, these methods suffer from running the reaction under the inert conditions[2,3] or in a high pressure reactor[4], being reactive only to the electron rich aromatic nucleus[3,5] or limited substrates[6-9], and using a stoichiometric amount of reagents[10]. So it is necessary to explore a common convenient method for allylation of the aromatics.

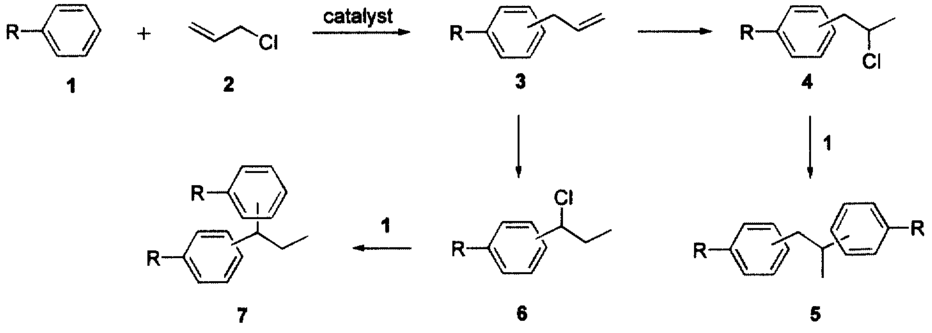

Figure 1. Friedel-Crafts type allylation mechanism.

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The chemistry of metallic indium is of current interest in organic synthesis due to its meditation ability for Barbier-type allylation reactions in water.[11-14] Our continuous efforts in the area of indium[15] led us to find out that indium is effective as a catalyst for allylation of aromatic compounds with allyl chloride which was previously unobserved. We wish to describe herein a mild and convenient allylation reaction of various kinds of aromatics with allylic chlorides catalyzed by indium. Thus treatment of the compound **1** with the allylic chloride **2** in the presence of a catalytic amount of indium at 70~80℃ for 2~7 hr resulted in formation of the corresponding mono-allylated product **3** as a major product in moderate to good yields accompanied with a mixture of chlorinated products **4** and **6** in 3~10% yields and trace amounts of diaryl-substituted alkanes **5** and **7** (**Figure 1**). The formation of the by-products is due to further reaction of liberating hydrogen chloride during the reaction with the double bond of the initially formed allylated product. An optimum ratio of aromatic, allylic chloride and catalyst was about 10~15:1:0.01. The color change of the solution to yellow served as an indicator of termination of the reaction. The prolonged reaction resulted in decreasing the yields and increasing the hydrochlorinated side products. The result of indium catalyzed Friedel-Crafts type allylation reaction of the aromatics is shown in the Table I.

Table I

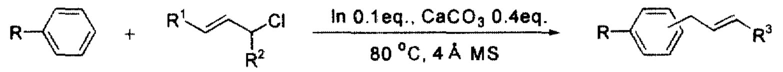
Entry	R	R^1	R^2	$R^{3\,a}$	Temp (℃)	Time (hr)	Yield (%)^b (ortho:para)^c
1	H	Me	H	Me	70	2	38
2	〃	H	Me	Me	70	4	42
3	1.4-dimethyl	H	H	H	80	4	45
4	〃	Me	H	Me	70	3	59
5	〃	H	Me	Me	70	3	90
6	F	H	Me	Me	70	2.5	45(5.5:1)
7	OH	Me	H	Me	25	24	61(1:3)
8	OMe	Me	H	Me	40	4	62(1:3)

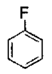
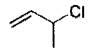
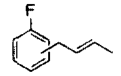
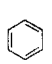
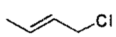
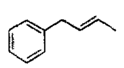
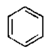
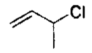
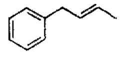
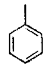
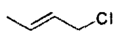
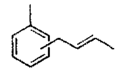
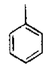
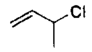
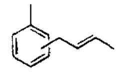
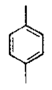
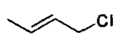
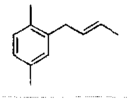
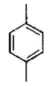
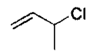
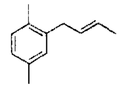
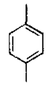
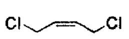
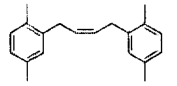
a: identified by ^{1}H NMR, ^{13}C NMR Spectroscopy and GC-MS; *b*: analyzed by GLC with an appropriate internal standard; *c*: measured by ^{1}H NMR Spectroscopy.

As can be seen in the Table I, even low reactive aromatics can be effectively allylated (entry 6). The electron density on aromatic ring was shown to considerable effect on the reaction as phenol could be allylated even at room temperature. The reaction of phenol under these reaction conditions proceeded without detection of any *O*-allylated product to give *para*-allylated phenol as a major product in contrast to the previously reported result[3] providing exclusively the *ortho*-substituted product. Attempted allylation of aniline was unsuccessful to give only a mixture of the *N*-allylaniline and *N,N*-diallylaniline. All of the reactions occurred regiospecifically at the α-position of the allylic group except the reaction with 3-chloro-1-butene. From this observation, we assume the mechanism for this reaction that indium just acts as a Lewis acid catalyst and allylic indium sesquihalides,[16] usually affording high γ-regioselectivity, is not involved as an intermediate since the reaction is running in less polar solvents. Also we could exclude the possibility of $InCl_3$ formation, which might catalyze the Friedel-Crafts allylation,[17,18] during the reaction from indium and allyl chloride since the recovered indium residue did not contain any trace of $InCl_3$. This is the first report that indium metal acts as a Lewis acid catalyst. The use of increased amounts (10 times) of the catalyst neither improved the yield nor changed the ratio of products, only reduced the reaction time by the factor 2. It is noteworthy that the recovered indium after the reaction is reusable without loss of activity.

In spite of experimental simplicity and using a catalytic amount of indium which make the present method convenient and useful, this procedure is still limited in scope of reaction yields. To overcome this shortage, it was necessary to remove hydrogen chloride formed during the reaction to avoid unwanted side reactions. A number of different solid bases were

Table II



Entry	Aromatic	Substrate	Product[a]	In (eq.)	Mol. Sieves (wt. %)	Time (hr)	Yields (%)[b] (ortho:para)[c]
1				0.1	5	3.5	37 (5.5:1)
2				0.1	-	2.5	61 (5.5:1)
3				K_2CO_3/Al_2O_3(1/50) 50 wt.%		20	46
4				0.1	-	5	84
5				0.1	5	6	80
6				0.1	5	3	75 (1:1)
7				0.1	5	3	86 (1:1)
8				0.1	-	2	86
9				0.1	5	4.5	92
10				0.1	5	6	93
11[d]				0.2	10	48	89

a: identified by ^{1}H NMR, ^{13}C NMR Spectroscopy and GC-MS; *b*: analyzed by GLC with an appropriate internal standard; *c*: determined by ^{1}H NMR Spectroscopy; *d*: the amount of used $CaCO_3$ was 0.5 eq..

investigated as a scavenger of hydrogen chloride and H_2O and it was found that the system consisting of $CaCO_3$/4Å molecular sieves was the choice of a solid base for clean formation of the allylated products in high yields. The reaction of the aromatic compounds with allylic chloride in the presence of 10 M% of indium, 40 M% of $CaCO_3$, and 5 wt. % of 4Å molecular sieves gave the corresponding allylated products in good yields. The result is shown in the Table II. The addition of the solid base actually deactivated the catalyst and caused a longer reaction time significantly. Employing further addition of indium enhanced the rate of the reaction. Using the system of $CaCO_3$/4Å molecular sieves as a solid base was superior to using the reported K_2CO_3-Al_2O_3 system[8] in respect to yields, the preparational simplicity and the amount of the used base. Separate experiments of the reaction in the absence of molecular sieves yielded the corresponding product in satisfactory yields. The high yields of the reaction under an open vessel, using a catalytic amount of indium which is reusable after the work-up without loss of its activity, and simplicity of the reaction procedure offer advantages over the existing allyation methods. A typical procedure is as follows. To a solution of crotyl chloride (2.21mmol) added in *p*-xylene (3ml, 24.5mmol), 10 M% of indium powder (-100mesh, 0.25g), $CaCO_3$ (0.85g, 40 M%) and 4Å molecular sieves (10mg, 5 wt. %) were added. The reaction mixture was heated at 80℃ for 4.5 hr until the color of the solution turned deep yellow. The solution was cooled to room temperature and analyzed by GC with an appropriate internal standard.

In conclusion we have demonstrated a mild and general method for preparation of allylated aromatic compounds, which are important in synthetic organic chemistry and industry, catalyzed by indium in the presence of $CaCO_3$/4Å molecular sieves. The further extension of utility of indium metal is under study in this lab.

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