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Rearrangement of Allyl Homoallyl Ethers to γ,δ-Unsaturated Carbonyl Compounds Catalyzed by Iridium Complexes

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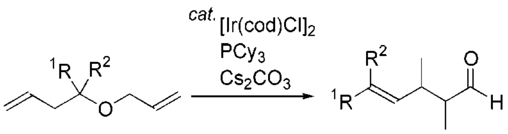
ABSTRACT



Iridium complexes were found to promote the conversion of allyl homoallyl ethers to γ,δ-unsaturated carbonyl compounds. For example, treatment of 1-allyl-1-allyloxycyclohexane in the presence of catalytic amounts of $[Ir(cod)Cl]_2$, PCy_3, and Cs_2CO_3 in toluene at 100 °C afforded 4-cyclohexyliden-2,3-dimethylbutanal in 74% yield. The reaction presumably proceeds through double bond migration to allyl vinyl ethers, which then undergo the Claisen rearrangement.

The aliphatic Claisen rearrangement of allyl vinyl ethers has been adopted as a valuable synthetic tool for the synthesis of γ,δ-unsaturated carbonyl compounds, although the availability of the starting vinyl ethers is rather difficult.[1] Therefore, the Claisen rearrangement is frequently carried out through the in situ generation of allyl vinyl ethers derived from β-allyloxyacrylic acids,[2] the reaction of allyl formates with the Tebbe reagent,[3] and the acid-catalyzed reaction of diallyl acetals,[4] as well as the transition metal compound- or acid-catalyzed transvinylation between alkyl vinyl ethers and allylic alcohols.[5] Diallyl ethers are reported to be converted into γ,δ-unsaturated aldehydes by heating in the presence of $(Ph_3P)_3RuCl_2$[6] or $[(C_8H_{12})Ir(PCH_3Ph_2)_2]PF_6$,[7] although these reactions must be carried out at higher temperature (>160 °C).

We have now found that an $[Ir(cod)Cl]_2$ complex catalyzes easily the transformation of allyl homoallyl ethers to γ,δ-unsaturated aldehydes under relatively mild conditions.

A typical reaction was carried out as follows. To a toluene solution (0.5 mL) of $[Ir(cod)Cl]_2$ (0.005 mmol), PCy_3 (0.01 mmol), and Cs_2CO_3 (0.005 mmol) was added allyl homoallyl ether (0.5 mmol) under Ar, and the mixture was stirred at 100 °C for 15 h. After quenching with wet ether, the products were isolated by column chromatography (230−400 mesh silica gel, hexane).

1-Allyl-1-allyloxycyclohexane (**1**) was chosen as a model substrate and reacted in the presence of a catalytic amount

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Table 1. Reaction of 1-Allyl-1-allyloxycyclohexane (**1**) Catalyzed by [Ir(cod)Cl]$_2$ under Selected Conditions^a

				yield (%)	
entry	phosphine	base	convn (%)	**2**	**3**
1	PCy$_3$	Cs$_2$CO$_3$	91	74	6
2			27	0	18
3	PCy$_3$		38	0	30
4		Cs$_2$CO$_3$	66	43	19
5^b	PCy$_3$	Cs$_2$CO$_3$	67	42	13
6	PPh$_3$	Cs$_2$CO$_3$	68	54	10
7	PCy$_3$	Na$_2$CO$_3$	45	31	11

[a] Compound **1** (0.5 mmol) was allowed to react in the presence of a catalytic amount of [Ir(cod)Cl]$_2$ (0.005 mmol), phosphine (0.01 mmol), and base (0.005 mmol) in toluene (0.5 mL) at 100 °C for 15 h under Ar. [b] PCy$_3$ (0.02 mmol) was used.

of [Ir(cod)Cl]$_2$ (eq 1). Table 1 summarizes the representative results for the reaction of **1** under selected reaction conditions. Treatment of **1** with [Ir(cod)Cl]$_2$ (1 mol %), PCy$_3$ (2 mol %), and Cs$_2$CO$_3$ (1 mol %) in toluene at 100 °C for 15 h gave 4-cyclohexyliden-2,3-dimethylbutanal (**2**) in 74% yield together with a small amount of 1-allyl-1-propenyloxycyclohexane (**3**) (entry 1). The reaction may be initiated by the double bond migration of **1** to 1-propenyl-1-propenyloxycyclohexane (**A**) through the formation of **3**, and the resulting **A** undergoes Claisen rearrangement to give **2**. The reaction in the absence or excess use of PCy$_3$ retarded the rearrangement of **1** to **2** (entries 2−5). When PPh$_3$ and Na$_2$CO$_3$ were used instead of PCy$_3$ and Cs$_2$CO$_3$, respectively, **2** was obtained in moderate yield (entries 6 and 7).

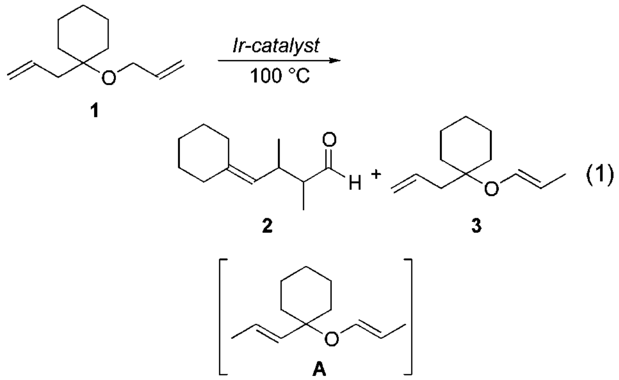
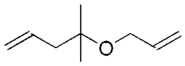
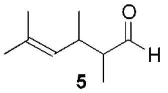
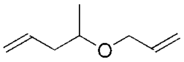
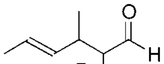
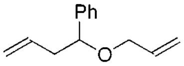
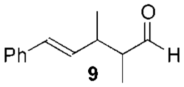
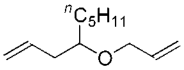
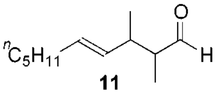
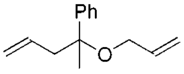
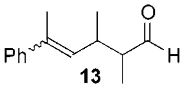
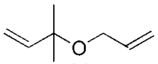
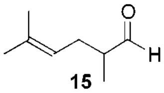
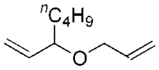
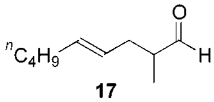
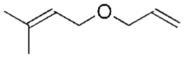
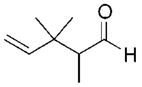


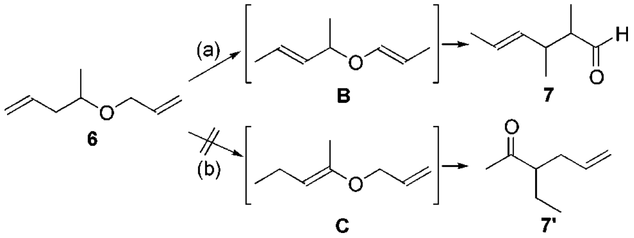
Table 2. Reaction of Various Allyl Homoallyl Ethers and Diallyl Ethers Catalyzed by [Ir(cod)Cl]$_2$^{a}

entry	substrate	product	yield (%)
1	 **4**	 **5**	68
2	 **6**	 **7**	78
3	 **8**	 **9**	81
4	 **10**	 **11**	72
5	 **12**	 **13**	81^b
6	 **14**	 **15**	78
7	 **16**	 **17**	48
8^c	 **18**	 **19**	78

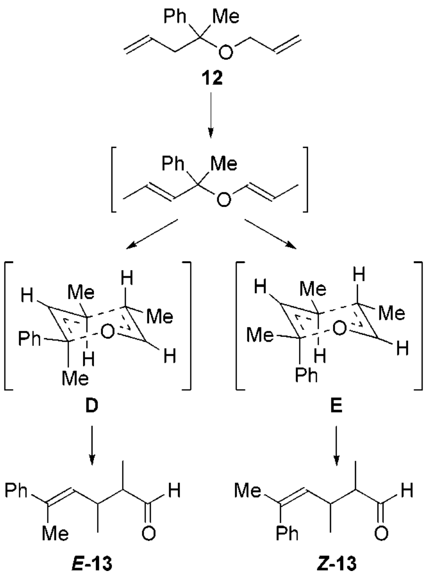
[a] Reactions were run in the same conditions as shown in Table 1. [b] The ratio of (*E*)-**13**/(*Z*)-**13** was 2/1. [c] Substrate was allowed to react in *p*-xylene at 140 °C for 15 h under Ar.

On the basis of these results, various allyl homoallyl ethers were converted into γ,δ-unsaturated aldehydes by the [Ir(cod)Cl]$_2$/PCy$_3$/Cs$_2$CO$_3$ system (Table 2, entries 1−5). These reactions produced the Claisen rearranged products in moderate to good yields. For example, 4-allyloxy-4-methylpentene (**4**) gave 2,3,5-trimethyl-4-hexenal (**5**) in 68% yield (entry 1). It is interesting to note that 4-allyloxypentene (**6**) was converted into (*E*)-2,3-dimethyl-4-hexenal (**7**) without the formation of the *Z*-isomer (entry 2). Similarly, allyl homoallyl ethers, **8** and **10**, led to the corresponding γ,δ-unsaturated aldehydes, **9** and **11**, respectively, in good selectivities (entries 3 and 4). In these reactions, it is noteworthy that the rearrangement took place in regio- and stereoselective fashion to give the sole rearranged product having *E*-geometry. For instance, from the allyl homoallyl ether **6**, 3-ethyl-5-hexen-2-one (**7′**) is expected to be formed through an alternative path (b), but no such compound was formed at all (Scheme 1). However, 4-allyloxy-4-phenylpentene (**12**) led to a 2:1 stereoisomeric mixture of (*E*)- and (*Z*)-2,3-dimethyl-5-phenyl-4-hexenal (**13**), whose ratio may be dependent on the free-energy difference between the six-membered transition states (**D**) and (**E**), which are assumed in the common aliphatic Claisen rearrangement (entry 5, Scheme 2).[1b]

Scheme 1



Scheme 2



The rearrangement of diallyl ethers to the corresponding γ,δ-unsaturated carbonyl compounds was also promoted under the influence of an Ir complex. The reaction of 3-allyloxy-3-methylbutene (**14**) and 3-allyloxyheptene (**16**) in the presence of $[Ir(cod)Cl]_2$, PCy_3 and Cs_2CO_3 at 100 °C for 15 h afforded 2,5-dimethyl-4-hexenal (**15**) and (*E*)-2-methyl-4-nonenal (**17**) in 78% and 48% yields, respectively (entries 6 and 7). 1-Allyloxy-3-methyl-2-pentene (**18**) gave 2,3,3-trimethyl-4-pentenal (**19**) in satisfactory yield (78%), although the reaction was carried out at 140 °C.

In summary, various types of γ,δ-unsaturated carbonyl compounds were prepared by the reaction of allyl homoallyl ethers or diallyl ethers in the presence of a catalytic amount of $[Ir(cod)Cl]_2$ combined with PCy_3 and Cs_2CO_3. The reaction seems to proceed through double bond migration followed by the Claisen rearrangement, though more detail mechanistic studies are now underway. Since the preparation of allyl homoallyl ethers is carried out more easily than that of allyl vinyl ethers, the present method provides a novel route to γ,δ-unsaturated aldehydes that are difficult to prepare by the conventional methods.

Supporting Information Available: The experimental procedure and compound characterization data. This material is available free of charge via the Internet at http://pubs.acs.org.

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