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Rhodium-catalyzed direct aldol condensation of ketones: a facile synthesis of fused aromatic compounds

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Abstract—Cationic rhodium complex $[Cp^*Rh(\eta^6\text{-}C_6H_6)](BF_4)_2$ (**1**) acts as an efficient catalyst for direct aldol condensation of ketones. The method can be applied to one-pot synthesis of fused aromatic compounds from cyclic ketones via sequential C–C bond formations.

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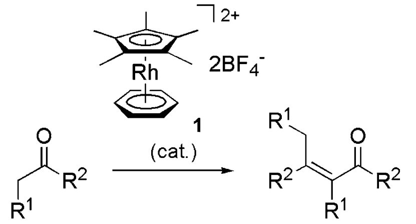
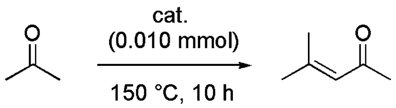
Rhodium-catalyzed carbon–carbon bond forming reactions have gained renewed interest in recent years.[1] Although reductive aldol-type reactions of enones with aldehydes have been widely performed with various rhodium catalysts,[2,3] direct aldol reactions of non-activated carbonyl compounds are limited to a few examples.[4] Herein, we wish to report direct aldol-type condensations of simple ketones with cationic rhodium complex catalysts (Eq. 1), and its application to a facile synthesis of fused aromatic compounds such as truxene derivatives.



(1)

Using acetone as a model substrate, direct aldol-type condensation was examined in the presence of various rhodium complex catalysts. As shown in Eq. 2, $[Cp^*Rh(\eta^6\text{-}C_6H_6)](BF_4)_2$ (**1**)[5] was proven to be a highly efficient catalyst for the formation of 4-methyl-3-pentene-2-one. Neutral complexes such as $RhCl_3$ and $(Cp^*RhCl_2)_2$ showed no catalytic activity. The condensation of various cyclic ketones proceeds efficiently in the presence of catalytic amount of **1** to give the corresponding enones. The representative results are summarized in Table 1. NOE experiments showed that the reactions of indanones gave *E*-isomers exclusively (entries 2–4). Intramolecular cyclocondensation of 2,5-hexanedione proceeds to give 2,5-dimethylfuran as a sole product (entry 5).



cat.	TON
$[Cp^*Rh(\eta^6\text{-}C_6H_6)](BF_4)_2$ (**1**)	170
$[Cp^*Rh(\eta^6\text{-}C_6H_6)](SbF_6)_2$	49
$[Cp^*Rh(\eta^6\text{-}C_6Me_6)](BF_4)_2$	19

(2)

The present method can be applied to one-pot synthesis of fused aromatic compounds by the sequential condensation of cyclopentanones (Table 2). The reaction of 1-indanone with 10 mol % of **1** gave truxene (**2**) (entry 2),[6] while similar treatment with 1 mol % of **1** afforded a mixture of **2** and the corresponding dimer product (*E*)-2-(1′-indenylidene)-1-indanone (entry 3). Substituted 1-indanones also gave the corresponding truxene derivative with high efficiency (entry 4). 1,1,1-Trifluoro-2,4-pentanedione undergoes similar type of double condensation to afford the corresponding phenol exclusively (entry 5). Triple condensation of cyclic ketones has been recognized as an efficient method for the preparation of polysubstituted benzenes, which are

Keywords: Aldol condensation; Rhodium catalyst.

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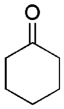
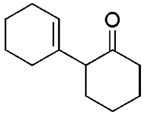
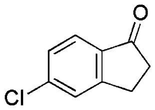
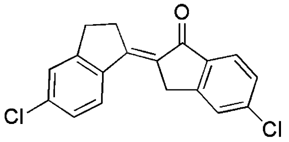
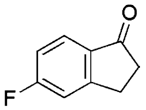
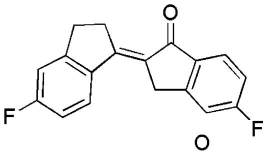
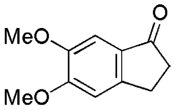
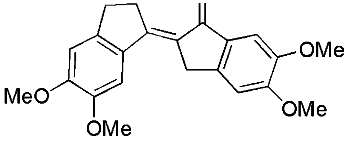
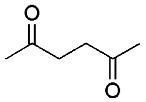
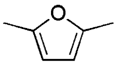
Table 1. Rhodium-catalyzed aldol condensation of ketones[a]

Entry	Substrate	Product	Yield (%)
1			61[b]
2			79[c] 86[c,d]
3			68[c]
4			67[c]
5			90

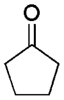
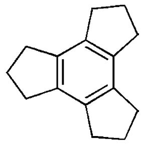
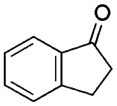
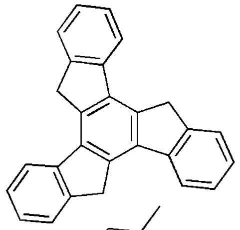
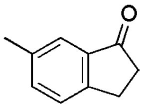
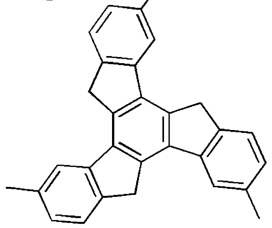
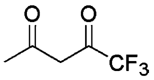
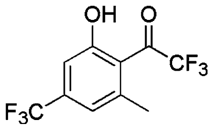
[a] A mixture of ketones and **1** (5 mol %) was stirred at 200 °C for 5 h without solvent.

[b] The reaction temperature was 150 °C.

[c] *E*-isomers were produced exclusively.

[d] 20 mol % catalyst.

Table 2. Synthesis of fused aromatic compounds[a]

Entry	Substrate	Product	Yield (%)
1			42[b]
2		 **2**	78
3			54[c,d]
4			92[e]
5			18

[a] A mixture of ketones and **1** (10 mol %) was stirred at 200 °C for 5 h without solvent.

[b] The reaction temperature was 150 °C.

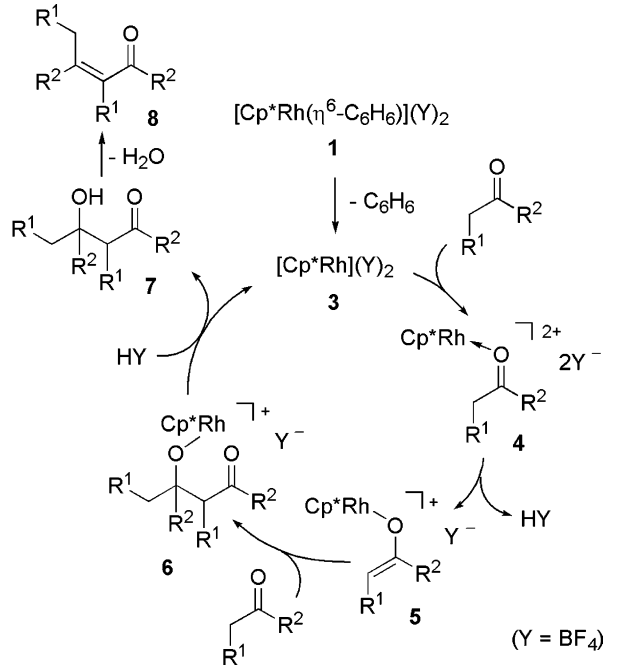
[c] 1 mol % catalyst.

[d] *E*-2-(1′-Indenylidene)-1-indanone was also produced in 42% yield.

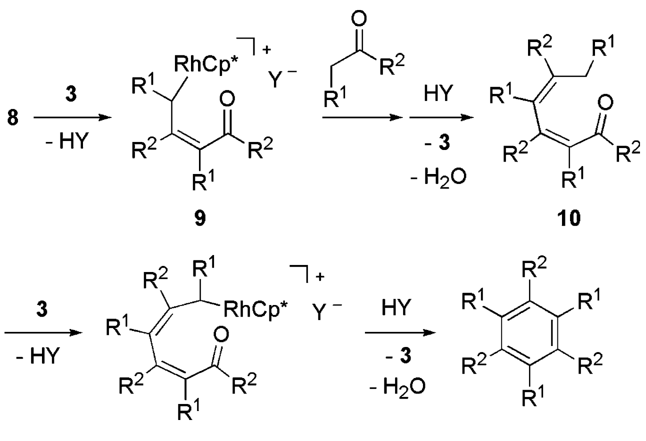
[e] 20 mol % catalyst.

important starting materials for polyaromatic electronic devices.[7] However, the conventional methods often require strong acids.[8] The present reaction provides an alternative and convenient method because of simple operation and neutral reaction conditions.

The reaction can be rationalized by assuming the mechanism as shown in Scheme 1. The catalytically active species seems to be coordinatively unsaturated cationic rhodium complex **3**, which would be formed by dissociation of η^6-arene ligand.[5] After coordination to ketones, the resulting complex **4** undergoes α-proton abstraction from the coordinated ketone to afford rhodium enolate **5** with releasing HBF_4. Catalytic inactivity of HBF_4 has been confirmed by the control experiments. Enolate **5** reacts with the substrate ketone to give aldolate intermediate **6**.[9] Proton abstraction from HBF_4 proceeds to regenerate the active species **3** with the formation of **7**, which undergoes dehydration to afford product **8**.



Scheme 1.



Scheme 2.

The formation of fused aromatic compounds can be explained by the polycondensation as shown in Scheme 2. Compound **8** would be converted into intermediate **9** via coordination of **3**, γ-proton abstraction by counter anion,[10] and *O*-to-*C* migration of rhodium. Condensation with ketones affords dienone **10**, which undergoes similar reaction sequence or direct electrocyclic reaction to afford aromatic compounds.

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References and notes

1. (a) Fagnou, K.; Lautens, M. *Chem. Rev.* **2003**, *103*, 169–196; (b) Hayashi, T.; Yamasaki, K. *Chem. Rev.* **2003**, *103*, 2829–2844; (c) Matsuda, I. In *Modern Rhodium-Catalyzed Organic Reactions*; Evans, P. A., Ed.; Wiley-VCH: Weinheim, 2005; pp 111–128.
2. Sato, S.; Matsuda, I.; Shibata, M. *J. Organomet. Chem.* **1989**, *377*, 347–356.
3. Hydrosilane: (a) Taylor, S. J.; Duffey, M. O.; Morken, J. P. *J. Am. Chem. Soc.* **2000**, *122*, 4528–4529; (b) Nishiyama, H.; Shiomi, T.; Tsuchiya, Y.; Matsuda, I. *J. Am. Chem. Soc.* **2005**, *127*, 6972–6973; Molecular hydrogen: (c) Jang, H.-Y.; Huddleston, R. R.; Krische, M. J. *J. Am. Chem. Soc.* **2002**, *124*, 15156–15157.
4. Cyanoacetates: (a) Kuwano, R.; Miyazaki, H.; Ito, Y. *J. Organomet. Chem.* **2000**, *603*, 18–29; Simple ketones: (b) Aoyama, Y.; Tanaka, Y.; Yoshida, T.; Toi, H.; Ogoshi, H. *J. Organomet. Chem.* **1987**, *329*, 251–266.
5. White, C.; Thompson, S. J.; Maitlis, P. M. *J. Chem. Soc., Dalton Trans.* **1977**, 1654–1661.
6. Typical procedure: In a 25 mL sealed tube, 1-indanone (132 mg, 1.0 mmol) and $[Cp^*Rh(\eta^6-C_6H_6)](BF_4)_2$ (**1**, 49 mg, 0.10 mmol) were placed and stirred at 200 °C for 5 h under argon atmosphere. After addition of ethanol (ca. 10 mL) and filtration, truxene **2** was obtained as an analytically pure microcrystals (103 mg, 78%).
7. (a) Pei, J.; Wang, J.-L.; Cao, X.-Y.; Zhou, X.-H.; Zhang, W.-B. *J. Am. Chem. Soc.* **2003**, *125*, 9944–9945; (b) Cao, X.-Y.; Zhou, X.-H.; Zi, H.; Pei, J. *Macromolecules* **2004**, *37*, 8874–8882; (c) Kanibolotsky, A. L.; Berridge, R.; Skabara, P. J.; Perepichka, I. F.; Bradley, D. D. C.; Koeberg, M. *J. Am. Chem. Soc.* **2004**, *126*, 13695–13702.
8. HCl: (a) Dehmlow, E. V.; Kelle, T. *Synth. Commun.* **1997**, *27*, 2021–2031; H_2SO_4: (b) Barker, C. C.; Emmerson, R. G.; Periam, J. D. *J. Chem. Soc.* **1958**, 1077–1080; $TiCl_4$: (c) Li, Z.; Sun, W.-H.; Jin, X.; Shao, C. *Synlett* **2001**, *12*, 1947–1949; Cp_2ZrCl_2: (d) Shirai, H.; Amano, N.; Hashimoto, Y.; Fukui, E.; Ishii, Y.; Ogawa, M. *J. Org. Chem.* **1991**, *56*, 2253–2256; $SiCl_4$: (e) Elmorsy, S. S.; Pelter, A.; Smith, K.; Hursthouse, M. B.; Ando, D. *Tetrahedron Lett.* **1992**, *33*, 821–824.

9. (a) Slough, G. A.; Bergman, R. G.; Heathcock, C. H. *J. Am. Chem. Soc.* **1989**, *111*, 938–949; (b) Slough, G. A.; Hayashi, R.; Ashbaugh, J. R.; Shamblin, S. L.; Aukamp, A. M. *Organometallics* **1994**, *13*, 890–898.
10. (a) Song, J.-S.; Szalda, D. J.; Bullock, R. M. *Organometallics* **2001**, *20*, 3337–3346; (b) Romeo, R.; Nastasi, N.; Scolaro, L. M.; Plutino, M. R.; Albinati, A.; Macchioni, A. *Inorg. Chem.* **1998**, *37*, 5460–5466.