An unusual dimerization of primary unsaturated alcohols catalyzed by $RuHCl(CO)(PPh_3)_3$†

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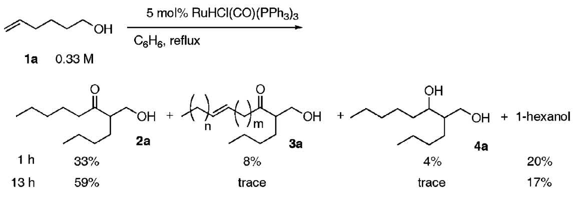
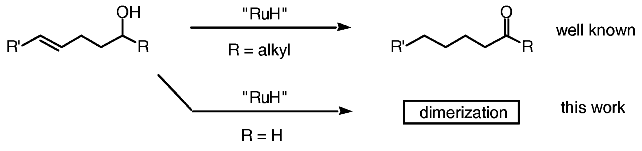
When primary unsaturated alcohols were treated with a catalytic amount of $RuHCl(CO)(PPh_3)_3$ in benzene under reflux, dimerization reactions took place to give α-hydroxymethyl ketones as major product.

The isomerization of carbon–carbon double bonds, a process catalyzed by metal hydride complexes *via* hydrometalation and subsequent β-hydride elimination, is among the most familiar reactions in transition metal chemistry.[1] Ruthenium hydride complexes are used in such alkene-isomerization reactions,[2–4] in which $RuHCl(CO)(PPh_3)_3$ is the most frequently used catalyst.[3] While the isomerization of secondary unsaturated alcohols to the corresponding saturated ketones by HRu-catalysts is known (Scheme 1),[4] remarkably, to the best of our knowledge, isomerization reactions of *primary* unsaturated alcohols have not been investigated in any detail.[4a,e,5] In this communication we report that *primary* unsaturated alcohols, when treated with a catalytic amount of $RuHCl(CO)(PPh_3)_3$, undergo an unusual dimerization to give α-hydroxymethyl ketones as the major product.

Treatment of 5-hexen-1-ol (**1a**) with $RuHCl(PPh_3)_3$ and $RuH_2(CO)(PPh_3)_3$, resulted in the isomerization of the C–C double bond to give a mixture of hexenols, while hexanal was formed in only trace amounts with these catalysts. In contrast, when a 0.33 M benzene solution of 5-hexen-1-ol (**1a**) was treated with 5 mol% of $RuHCl(CO)(PPh_3)_3$ for 1 h at reflux, a mixture of 5-hydroxymethyl-6-undecanone (**2a**) and the related unsaturated products **3a** were obtained in 33% and 8% yields, respectively (eqn (1)). The crude mixture also contained the saturated alcohol, 1-hexanol and diol **4a**, the reduced form of **2a**.[6] Interestingly, however, when the reaction time was extended to 13 h, the yield of α-hydroxymethyl ketone **2a** increased to 59%, whereas the yield of **3a** and **4a** diminished to the level of trace amounts. It seems likely that **3a** and **4a** were converted to **2a** under the reaction conditions.



(1)



Scheme 1 Ru–H catalyzed reaction of unsaturated alcohols.

Table 1 summarizes results of RuH-catalyzed dimerization of unsaturated alcohols. Dimerization of the isomeric hexenyl alcohols **1b**, **1c**, **1d**, **1e** and **1f** under similar conditions (0.33 M, 5 mol% $RuHCl(CO)(PPh_3)_3$, benzene reflux, 13 h) also occurs to give the same product **2a** in similar yields (entries 1–5). Both *cis* and *trans* isomers underwent a smooth dimerization. On the other hand, no dimerization was observed with the secondary alcohol **1g**, which underwent the isomerization to 3-hexanone (**5**) (entry 6).[7] Thus, the dimerization of primary hexenols proceeds irrespective of the position or the *E*- or *Z*-geometry of the double bonds.

The reaction of unsaturated alcohol **1i**, which contains a longer substituent at the 3-position, gave the saturated dimer **2i** in 33% yield together with a significant amount of unsaturated dimer **3i**, in which the position of the C–C double bond was dispersed into the longer carbon chain (entry 8). The subsequent treatment of the mixture of **2i** and **3i** with hydrogen and a Pd/C catalyst gave **2i** as the sole dimerization product. The experimental result of **1i**, which was obtained at a low concentration (0.017 M), which is 20 times lower than the standard concentration, is interesting, since decanal (**7**) and an isomeric mixture of decenals **8** were obtained in significant amounts (entry 9). This result proposes that a double bond migration reaction of **1i** would take place to give **7**, whereas allylic alcohol **1i** would also serves as the hydrogen source of transfer hydrogenation to be converted into 2-decenal.[8,9] Cinnamyl alcohol (**1j**) also underwent dimerization to give a mixture of **2j** and **3j** (entry 10).

Following up the above observation, we propose a rationale for the dimerization of **1a** to **2a** based on an Ru-aldol reaction[10] and transfer hydrogenation (Scheme 2). Thus, as a consequence of ruthenium hydride-mediated isomerization of a C–C double bond, aldehyde **B** would be formed *via* allylic alcohol **A**. Transfer hydrogenation of **B** with **A** would produce α,β-unsaturated aldehyde **C** and n-hexanol. Hydroruthenation of **C** would produce ruthenium enolate **D**, which then undergoes aldol reaction with **B** to give **F** *via* **E**. Transfer hydrogenation of **F** with **A** provides the dimerization product **2a** and α,β-unsaturated aldehyde **C**. A similar scenario based on aldol reaction of **D** with **C** may account for the formation of unsaturated by-product **3a**.

In summary, we have found that $RuHCl(CO)(PPh_3)_3$ catalyzes the dimerization of unsaturated primary alcohols leading to the

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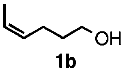
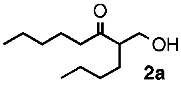
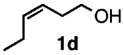
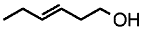
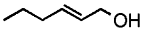
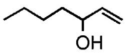
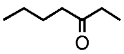
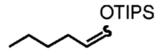
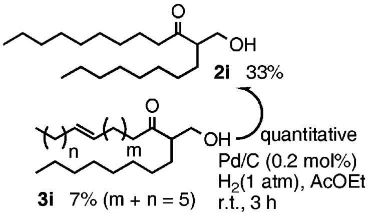
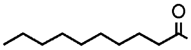
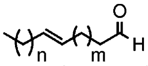
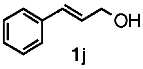
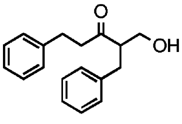
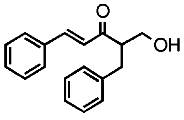
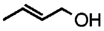
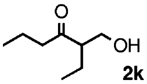
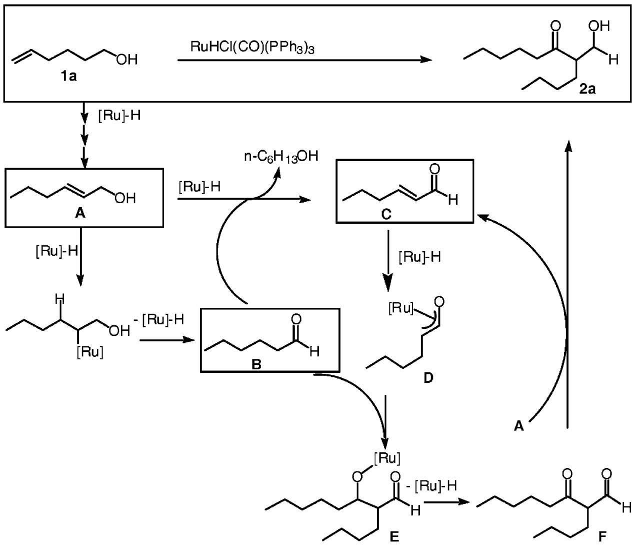
Table 1 Representative examples of Ru–H catalyzed dimerization of primary unsaturated alcohols[a]

Entry	Unsaturated alcohol **1**	Products (yield[b])
1	 **1b**	 **2a** 55%
2	 **1c**	**2a** 56%
3	 **1d**	**2a** 52%
4	 **1e**	**2a** 58%
5	 **1f**	**2a** 58%
6	 **1g**	 **5** 65%
7	 **1h**	 [c] **6** 79% (E/Z = 29/71)
8	 **1i**	 **2i** 33% quantitative Pd/C (0.2 mol%) H_2(1 atm), AcOEt r.t., 3 h **3i** 7% (m + n = 5)
9[d]	**1i**	**2i** 19% **3i** 4%  **7** 33%  **8** 11% (m + n = 5)
10	 **1j**	 **2j** 37%  **3j** 12%
11[e,f]	 **1k**	 **2k** 41%

[a] General Conditions: [**1**] = 0.33 M, $RuHCl(CO)(PPh_3)_3$ (5 mol%), C_6H_6, reflux, 13 h. [b] Isolated yield. [c] Determined by ^1H NMR. [d] [**1i**] = 0.017 M. [e] 10 mol% of $RuHCl(CO)(PPh_3)_3$ was used. [f] 2-Ethylhexane-1,3-diol was obtained in 13% yield as a by-product.



Scheme 2 A possible reaction mechanism for the dimerization of **1a**.

formation of α-hydroxymethyl ketones. Formation of ruthenium enolates and aldol reaction with aldehydes was proposed as a rationale to account for the unusual reaction. Further detailed mechanistic studies as well as optimization of the dimerization reaction are currently being pursued in our laboratory.

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Notes and references

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6 A mixture of unsaturated diols, reduced form of **3a**, was also detected (total yields: <4%).

7 We also tested the reaction of hexanal under the same reaction conditions. The dimerization is not viable for hexanal alone. The reaction was very sluggish and unreacted hexanal was recovered, along with a small amount of the Tischenko type ester (3%) and 1-hexanol (2%).

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