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# Metallic Dysprosium Promoted Allylation of Carbonyl Compounds in the Presence of Mercuric Chloride

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ABSTRACT: *Dysprosium metal promoted Barbier-type allylation of ketones and aldehydes has been investigated. It has been shown that dysprosium metal (activated by mercuric chloride) is effective in promoting the reaction of ketones with allyl iodide. The corresponding homoallylic alcohols are obtained in satisfactory yields. This reaction is regioselective and chemoselective. An* **α, β***-unsaturated ketone affords a 1,2-addition product selectively. Reactive groups (such as Cl, Br, and methoxy) of aromatic ketones remain unchanged under the reaction conditions.* © 1998 John Wiley & Sons, Inc. Heteroatom Chem 9:475–478, 1998

## *INTRODUCTION*

In recent years, more and more attention has been paid to the utilization of lanthanides in organic synthesis. Some of the lanthanides [1], such as Ce [2], Sm [3], Yb [4], etc., have been successfully investigated. Up to the present, however, no reports have been found about the use of metallic dysprosium in organic reactions involving carbon–carbon bond formation. In view of the current interest in the field of organolanthanoid chemistry [3c,3d], we extended our work to the study of the synthetic use of metallic dysprosium. In this article, we report the Barbier-type allylation reactions of ketones promoted by dysprosium metal in the presence of mercuric chloride, which afford the corresponding homoallylic alcohols in good to excellent yields.

## *RESULTS AND DISCUSSION*

First, we carried out the reaction of *p*-chlorobenzaldehyde with allyl bromide in the mixed solvent of saturated aqueous $NH_4Cl$ solution and THF (volume ratio: 3/5). The reaction was complex, and several products were found by TLC. When the same reaction proceeded in anhydrous THF (Table 1, entry b), only the homoallylic alcohol was obtained in moderate yield. Therefore, the following reactions were all carried out in anhydrous THF. In order to optimize the reaction conditions, several reactions were investigated to examine the effect of the allyl halide, catalyst, temperature, and reaction time. The general reaction is depicted in Scheme 1, and some typical results are summarized in Table 1.

Without the assistance of $BF_3 \cdot Et_2O$ or $HgCl_2$, no homoallylic alcohol was found by TLC in the reactions of allyl bromide with *p*-chlorobenzaldehyde and acetophenone (entries a and d). When a catalytic amount of Lewis acid $BF_3 \cdot Et_2O$ was added (entries b, c, and e), both ketones and aldehydes gave the corresponding allylation products in moderate yields. While a catalytic amount of $HgCl_2$ was added in the reaction of acetophenone with allyl bromide, instead of $BF_3 \cdot Et_2O$ (entries f and g), the total yields were increased. Besides the predictable homoallylic alcohols, some pinacols were found in the products. Obviously, the coupling of ketones competed with the Barbier-type allylation. The mercuric chloride,

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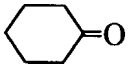
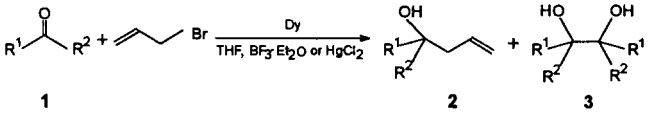
**TABLE 1** The Allylation of Ketones and Aldehydes with Allyl Bromide (and allyl iodide)

| *Entry* | *$R^1COR^2$* | *Allyl Halide* | *Substrate Molar Ratio ($R^1COR^2$/Allyl halide/Dy)* | *Conditions* | *Product (s)* | *Yield (%)*[a] |
|---|---|---|---|---|---|---|
| a | *p*-$ClC_6H_4CHO$ | $CH_2=CHCH_2Br$ | 1.0/2.0/3.0 | r.t. (24 h) | — | — |
| b | *p*-$ClC_6H_4CHO$ | $CH_2=CHCH_2Br$ | 1.0/3.0/4.0[b] | r.t. (24 h) | **2b** | 41 |
| c | $C_6H_5COC_6H_5$ | $CH_2=CHCH_2Br$ | 1.0/2.0/2.5[b] | r.t. (48 h) | **2c** | 46 |
| d | $C_6H_5COCH_3$ | $CH_2=CHCH_2Br$ | 1.0/2.0/2.5 | r.t. (24 h) | — | — |
| e | $C_6H_5COCH_3$ | $CH_2=CHCH_2Br$ | 1.0/2.0/2.5[b] | r.t. (24 h) | **2e** | 32 |
| f | $C_6H_5COCH_3$ | $CH_2=CHCH_2Br$ | 1.0/2.0/2.5[c] | r.t. (24 h) | **2f**<br>**3f** | 28<br>55 |
| g | $C_6H_5COCH_3$ | $CH_2=CHCH_2Br$ | 1.0/2.0/2.5[c,d] | 0°C (2 h), r.t. (22 h) | **2g**<br>**3g** | 65<br>26 |
| h |  | $CH_2=CHCH_2Br$ | 1.0/2.0/2.5[c,d] | 0°C (2 h), r.t. (22 h) | **2h** | 64 |
| i | $C_6H_5COCH_3$ | $CH_2=CHCH_2I$ | 1.0/2.0/2.5 | 0°C (2 h), r.t. (2 h) | — | —[e] |
| j | $C_6H_5COCH_3$ | $CH_2=CHCH_2I$ | 1.0/2.0/2.5[c] | 0°C (2 h), r.t. (2 h) | **2j** | 80 |

[a]Isolated yield. Structures of all the products were confirmed by $^1H$ NMR and IR spectroscopy.
[b]A catalytic amount of $BF_3 \cdot Et_2O$ was added.
[c]A catalytic amount of $HgCl_2$ was added.
[d]Two molar eq. of NaI was added.
[e]62.5% of starting acetophenone was recovered.




1 2 3

**SCHEME 1**

which reacted with the powdered dysprosium to form the highly reactive dysprosium amalgam, functioned in this reaction as an initiator. The elemental mercury that formed during the reaction could be found at the bottom of the flask. The addition of mercuric chloride accelerated the reaction so greatly that the temperature of the reaction mixture rose quickly at the beginning of the reaction. Therefore, we then carried out the following reactions at 0°C for 2 hours. In entry f, pinacol was the main product, which demonstrated that the coupling was the primary reaction. The yield of homoallylic alcohol was low but could be increased considerably by addition of sodium iodide (entry g). Even so, the coupling reaction of the ketone, as a side reaction, still could not be neglected. However, when allyl iodide was used in the reaction instead of allyl bromide (entry j), the allylation product was obtained in good yield even when the reaction time was shortened to 4 hours, and no pinacol was isolated. It told us that the presence of mercuric chloride was indispensable. In the absence of mercuric chloride (entry i), no homoallylic alcohol was found, and over half of the starting ketone was recovered.

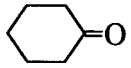
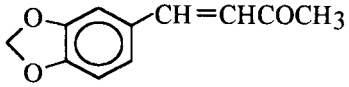
According to the foregoing results, it is clear that allyl iodide is a better allylation agent than allyl bromide in this reaction in both the reactivity and the selectivity, and the presence of mercuric chloride is necessary. Next we studied the Barbier-type allylation of ketones with allyl iodide promoted by metallic dysprosium in the presence of mercuric chloride.

A number of alkyl and aromatic ketones were utilized in our investigation, and the results are summarized in Table 2. The reactions proceeded smoothly at 0°C for 2 hours and then at room temperature for 2 hours, and the corresponding homoallylic alcohols were isolated in satisfactory yields (Scheme 2).

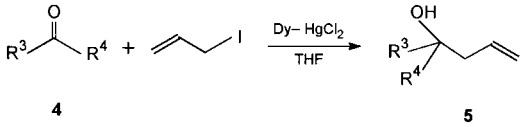
For aromatic ketones, the allylation afforded the corresponding homoallylic alcohols in good to excellent yields in the presence of either an electron-withdrawing (entries k and l) or electron-donating (entry m) substituent. Even for a ketone with high steric hindrance, such as benzophenone (entry n), the allyldiphenylcarbinol was obtained in good yield. Furthermore, aromatic ketones (entries j–n) were more reactive than aliphatic ketones (entries p and q) in the reaction. However, there was one exception, namely, 1,3-diphenylacetone (entry o). It was converted into 1-phenyl-2-benzyl-4-penten-2-ol in almost quantitative yield.

Besides its smoothness and rapidity, the reaction is also regioselective and chemoselective. An $\alpha,\beta$-unsaturated ketone (entry r) afforded a 1,2-addition product selectively. Also, the carbonyl group of ke-

**TABLE 2** The Allylation of Ketones with Allyl Iodide in the Presence of $HgCl_2$

| Entry | $R^3COR^4$ [a] | Product | Yield (%)[b] |
|---|---|---|---|
| j | $C_6H_5COCH_3$ | **5j** | 80 |
| k | *p*-$ClC_6H_4COCH_3$ | **5k** | 84 |
| l | *p*-$BrC_6H_4COCH_3$ | **5l** | 91 |
| m | *p*-$CH_3OC_6H_4COCH_3$ | **5m** | 84 |
| n | $C_6H_5COC_6H_5$ | **5n** | 87 |
| o | $C_6H_5CH_2COCH_2C_6H_5$ | **5o** | 94 |
| p | $CH_3COC(CH_3)_3$ | **5p** | 72 |
| q |  | **5q** | 74 |
| r |  | **5r** | 32 |
| s | *p*-$ClC_6H_4CHO$ | **5s** | 18 |

[a]The molar ratio of ketone (or aldehyde)/allyl iodide/Dy was always 1.0/2.0/2.5. A catalytic amount of $HgCl_2$ was added in every case.
[b]Isolated yield. The structures of all the products were confirmed by $^1H$ NMR and IR spectroscopy. The structure of a new compound (**5r**) was also confirmed by elemental analysis.




4 5

**SCHEME 2**

tones reacted smoothly, while other functional groups (such as Cl, Br, and methoxy) remained unchanged under the employed conditions.

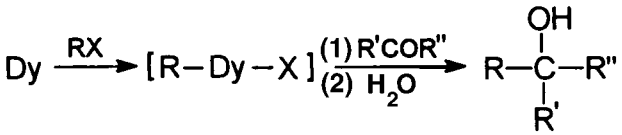
The present method was not suitable for the allylation of aldehydes. When aldehydes were used as substrates, the reaction products were more complex, and the yields of the homoallylic alcohol were low (entry s).

As for the reaction mechanism, we believe that it resembles that of the metallic samarium mediating Barbier-type reactions [3c]. First, the oxidation of dysprosium metal by the allyl halides forms the organodysprosium intermediates, which react with ketones immediately to produce the homoallylic alcohols (Scheme 3).

## *EXPERIMENTAL*

Elemental analyses were performed on a Perkin–Elmer 240C elemental analyzer. Infrared spectra were recorded on a Shimadzu IR 408 spectrophotometer. Nuclear magnetic resonance spectra were recorded on a JNM-PMX 60 SI (60 MHz, JEOL) spectrometer.

The metallic dysprosium used in the reactions




**SCHEME 3**

was prepared from a dysprosium ingot by carefully scraping it with a rasp. THF was treated with sodium and distilled before use. Ethyl acetate and petroleum ether used in the flash column chromatography were distilled before use.

### *Reaction of Ketones (or aldehydes) with Allyl Bromide*

To 10 mL of anhydrous THF were added the carbonyl compound (2 mmol), allyl bromide (4 mmol), powdered dysprosium (5 mmol), and mercuric chloride (150 mg) (or 0.15 mL $BF_3 \cdot Et_2O$). The mixture was stirred at room temperature for 24 hours. Then the reaction mixture was treated with 10 mL of water and extracted with ether. The combined organic extracts were dried over magnesium sulfate. After evaporation of the ether, the residue was purified by flash column chromatography, a mixture of petroleum ether and ethyl acetate (volume ratio of petroleum ether/ethyl acetate: 60/1 to 5/1) being used as the elution solvent, and from which the products were obtained.

### *Reaction of Ketones with Allyl Iodide*

A mixture of ketone (2 mmol), allyl iodide (4 mmol), dysprosium powder (5 mmol), mercuric chloride (150 mg), and anhydrous THF (10 mL) was stirred at 0°C for 2 hours and then at room temperature for 2 hours. After evaporation of the THF, the reaction mixture was treated with 10 mL of water and then extracted with ether. The combined organic extracts were dried over magnesium sulfate. After evaporation of the ether, the residue was purified by flash column chromatography, a mixture of petroleum ether and ethyl acetate (volume ratio of petroleum ether/ethyl acetate: 30/1 to 5/1) being used as elution solvent, and from which the products were isolated.

*1-(4-Chlorophenyl)-3-buten-1-ol p-*$ClC_6H_4CH(OH)CH_2CH=CH_2$ (**2b**) [5]. IR (neat): 3350 (s, O–H), 1630 (m, C=C), 910 (m, $C=CH_2$) $cm^{-1}$; $^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 1.93 (br, 1H, O<u>H</u>), 2.28 (m, 2H, $C\underline{H}_2CH=CH_2$), 4.43 (t, 1H, C<u>H</u>OH), 4.67–5.80 (m, 3H, $C\underline{H}=C\underline{H}_2$), 7.07 (m, 4H, $C_6\underline{H}_4$).

*1,1-Diphenyl-3-buten-1-ol* ($C_6H_5)_2C(OH)CH_2CH=CH_2$ (**2c**) [6]. IR (neat): 3550 (s, O–H), 1630 (m, C=C), 910 (m, $C=CH_2$) $cm^{-1}$; $^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 2.20 (br, 1H, O<u>H</u>), 2.87 (d, 2H, C<u>H</u>$_2$CH=CH$_2$), 4.80–5.90 (m, 3H, C<u>H</u>=C<u>H</u>$_2$), 7.15 (m, 10H, 2 × $C_6H_5$).

*2-Phenyl-4-penten-2-ol* $C_6H_5C(OH)(CH_3)CH_2CH=CH_2$ (**2e**) [7]. IR (neat): 3400 (s, O–H), 1630 (m, C=C), 910 (s, $C=CH_2$) $cm^{-1}$; $^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 1.40 (s, 3H, C<u>H</u>$_3$), 1.87 (br, 1H, O<u>H</u>), 2.43 (q, 2H, C<u>H</u>$_2$CH=CH$_2$), 4.67–5.80 (m, 3H, C<u>H</u>=C<u>H</u>$_2$), 7.10 (m, 5H, $C_6$<u>H</u>$_5$).

*2,3-Diphenyl-2,3-butadiol* $C_6H_5C(OH)(CH_3)C(OH)(CH_3)C_6H_5$ (**3f**) [8]. IR (nujol mull): 3400 (m, O–H) $cm^{-1}$; $^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 1.33 (s, 6H, 2 × C<u>H</u>$_3$), 2.30 (br, 2H, 2 × O<u>H</u>), 6.95 (S, 10H, 2 × $C_6$<u>H</u>$_5$).

*1-Allylcyclohexanol* (**2h**) [7]. IR (neat): 3350 (s, O–H), 1630 (m, C=C), 900 (m, $C=CH_2$) $cm^{-1}$;$^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 1.40 (s, 10H, 5 × C<u>H</u>$_2$), 1.56 (br, 1H, O<u>H</u>), 2.08 (d, 2H, C<u>H</u>$_2$CH=CH$_2$), 4.70–6.03 (m, 3H, C<u>H</u>=C<u>H</u>$_2$).

*2-(4-Chlorophenyl)-4-penten-2-ol p-*$ClC_6H_4C(OH)(CH_3)CH_2CH=CH_2$ (**5k**) [3c]. IR (neat): 3400 (s, O–H), 1630 (m, C=C), 910 (s, $C=CH_2$) $cm^{-1}$; $^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 1.40 (s, 3H, C<u>H</u>$_3$), 2.05 (br, 1H, O<u>H</u>), 2.38 (q, 2H, C<u>H</u>$_2$CH=CH$_2$), 4.70–5.85 (m, 3H, C<u>H</u>=C<u>H</u>$_2$), 7.16 (m, 4H, $C_6$<u>H</u>$_4$).

*2-(4-Bromophenyl)-4-penten-2-ol p-*$BrC_6H_4C(OH)(CH_3)CH_2CH=CH_2$ (**5l**) [2b]. IR (neat): 3400 (s, O–H), 1630 (m, C=C), 910 (s, $C=CH_2$) $cm^{-1}$; $^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 1.43 (s, 3H, C<u>H</u>$_3$), 1.93 (br, 1H, O<u>H</u>), 2.40 (q, 2H, C<u>H</u>$_2$CH=CH$_2$), 4.70–5.87 (m, 3H, C<u>H</u>=C<u>H</u>$_2$), 7.23 (m, 4H, $C_6$<u>H</u>$_4$).

*2-(4-Methoxyphenyl)-4-penten-2-ol p-*$CH_3OC_6H_4C(OH)(CH_3)CH_2CH=CH_2$ (**5m**) [2b]. IR (neat): 3400 (s, O–H), 1630 (m, C=C), 910 (m, $C=CH_2$) $cm^{-1}$; $^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 1.36 (s, 3H, C<u>H</u>$_3$), 2.20 (br, 1H, O<u>H</u>), 2.33 (q, 2H, C<u>H</u>$_2$CH=CH$_2$), 3.60 (s, 3H, OC<u>H</u>$_3$), 4.63–5.77 (m, 3H, C<u>H</u>=C<u>H</u>$_2$), 6.47–7.27 (m, 4H, $C_6$<u>H</u>$_4$).

*1,1-Dibenzyl-3-buten-1-ol* $(C_6H_5CH_2)_2C(OH)CH_2CH=CH_2$ (**5o**) [9]. IR (neat): 3550 (s, O–H), 1630 (m, C=C), 905 (s, $C=CH_2$) $cm^{-1}$; $^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 1.23 (br, 1H, O<u>H</u>), 2.03 (d, 2H, C<u>H</u>$_2$CH=CH$_2$), 2.58 (s, 4H, 2 × C<u>H</u>$_2$), 4.63–6.03 (m, 3H, C<u>H</u>=C<u>H</u>$_2$), 7.05 (s, 10H, 2 × $C_6$<u>H</u>$_5$).

*2,2,3-Trimethyl-5-hexen-3-ol* $CH_3C(CH_3)_2C(OH)(CH_3)CH_2CH=CH_2$ (**5p**) [10]. IR (neat): 3450 (s, O–H), 1630 (m, C=C), 900 (s, $C=CH_2$) $cm^{-1}$; $^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 0.90 [s, 9H, C(C<u>H</u>$_3$)$_3$], 1.02 (s, 3H, C<u>H</u>$_3$), 1.23 (br, 1h, O<u>H</u>), 2.12 (q, 2H, C<u>H</u>$_2$CH=CH$_2$), 4.70–5.97 (m, 3H, C<u>H</u>=C<u>H</u>$_2$).

*1-(3,4-Methylenedioxyphenyl)-3-methyl-1,5-henadien-3-ol* (**5r**). IR (neat): 3370 (s, O–H), 1630 (m, C=C), 915 (s, $C=CH_2$) $cm^{-1}$; $^1H$ NMR ($CCl_4$, HMDS as inner standard) $\delta$ 1.33 (s, 3H, C<u>H</u>$_3$), 1.73 (br, 1H, O<u>H</u>), 2.32 (d, 2H, C<u>H</u>$_2$CH=CH$_2$), 4.86–6.47 (m, 7H, C<u>H</u>=C<u>H</u>$_2$, O-C<u>H</u>$_2$-O, C<u>H</u>=C<u>H</u>), 6.50–7.07 (m, 3H, $C_6$<u>H</u>$_3$). Anal. calcd for $C_{14}H_{16}O_3$: C, 72.39; H, 6.94. Found: C, 72.30; H, 7.15.

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