Pergamon

Tetrahedron Letters 43 (2002) 3481–3484

TETRAHEDRON LETTERS

Catalytic aerobic oxidation of diols under photo-irradiation: highly efficient synthesis of lactols

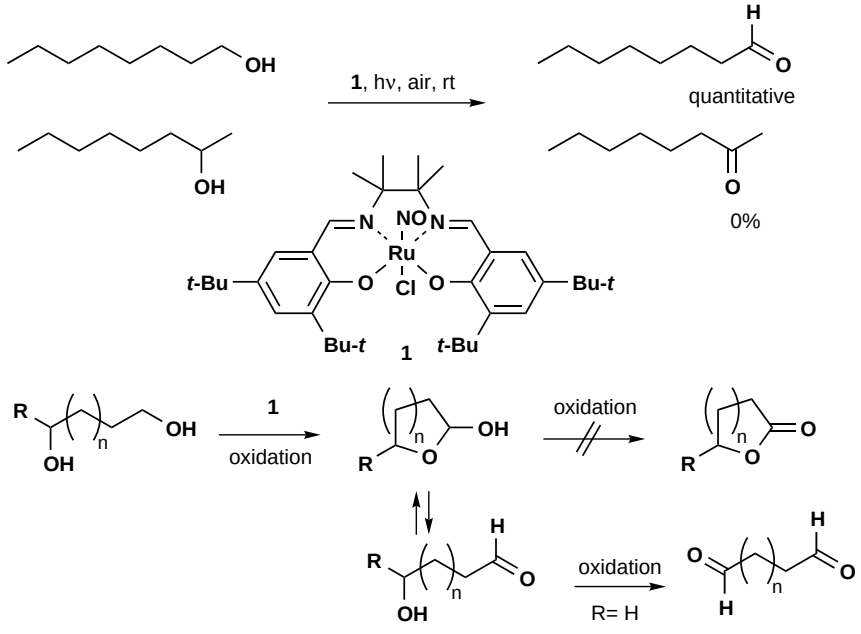
Atsushi Miyata, Mizuki Furukawa, Ryo Irie and Tsutomu Katsuki*

Department of Chemistry, Faculty of Science, Graduate School, Kyushu University 33 CREST, JST (Japan Science and Technology) Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan

Received 25 February 2002; accepted 22 March 2002

Abstract—Aerobic oxidation of 1,*n*- and 1,ω-diols with (ON)Ru(salen) **1** as the catalyst was found to give the corresponding lactols in almost quantitative yields. Furthermore, in the oxidation of 2,2-dimethylalkane-1,ω-diols, less sterically hindered ω-alcohols were found to be preferentially oxidized when (ON)Ru(salen) **6** was used as the catalyst. *n*-Decanol was preferentially oxidized in the presence of 2,2-dimethylpropanol also by using **6** as the catalyst. © 2002 Elsevier Science Ltd. All rights reserved.

We recently reported chemoselective aerobic oxidation of primary alcohols to the corresponding aldehydes[1–3] with (ON)Ru(salen) **1** as the catalyst in the presence of secondary alcohol, under photo-irradiation (Scheme 1). On the other hand, 1,*n*-diols are ordinary synthetic precursors of lactols that occur in many natural products as subunits and also serve as useful intermediates for organic synthesis. Nevertheless, conventional oxidation of 1,*n*-diols often give lactones, over-oxidation products of lactols,[4] together with the desired lactols except for several reactions.[5] We expected that (ON)Ru(salen)-catalyzed aerobic oxidation of 1,*n*-diols would give the corresponding lactols preferentially, because the lactols are secondary alcohols and should



Scheme 1.

Keywords: Ru(salen); aerobic oxidation; oxygen; diol; lactol; photo-irradiation.

* Corresponding author.

PII: S0040-4039(02)00605-6

not suffer over-oxidation (Scheme 1). It was, however, considered that the product would be a 1,ω-dial, when the starting material is a 1,ω-diol (R = H) and the resulting lactol is equilibrated with a hydroxy aldehyde.

With these expectations in mind, we first examined aerobic oxidation of 1,ω-diols by using (ON)Ru(salen) **1** as the catalyst (Scheme 2). Indeed, butane-1,4-diol and pentane-1,5-diol were oxidized to the corresponding lactols, accompanied with a small amount of dials. On the other hand, oxidation of hexane-1,6-diol gave 1,6-hexanedial exclusively, suggesting that the seven-membered lactol intermediate was equilibrated with 6-hydroxyhexanal. Formation of a trace amount (<1%) of lactones was detected in these reactions.

We also examined oxidation of 1,*n*-diols under the same conditions (Scheme 3). As expected from the previous results, the primary alcohols were oxidized exclusively to give mixtures of the corresponding *trans*- and *cis*-lactols, and oxidation of the secondary alcohols was not observed.

This aerobic oxidation has been considered to proceed through a coordinatively unsaturated Ru(IV) species **2** to which alcohol is coordinated and oxidized to the corresponding carbonyl compound (Scheme 4). Upon the coordination, primary alcohols suffer less steric repulsion with the axial methyl group than secondary alcohols and are oxidized selectively.[1]

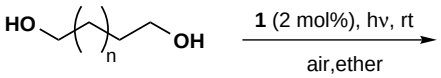
Naturally, the oncoming alcohol is considered to direct their alkyl moiety away from the axial methyl group. Therefore, when the Ru(salen) carries a bulky substituent at C3 and C3′, oxidation of primary alcohols is expected to become slower, as the alkyl moiety of the alcohols becomes bulkier. Thus, we examined oxidation of a 1:1 mixture of 1-octanol and neopentyl alcohol by using complexes **1**, **4**, and **5** as the catalyst (Scheme 5). The differentiation of non- and β-branched alcohols with **1** was unsatisfactory. As expected, the reaction with **4** bearing a bulky 2-phenylnaphthyl group at C3 and C3′ showed better selectivity (**A**:**B** = 9:1) but the reaction was slow. However, chemical yield of the aldehyde was considerably improved without severely vitiating the selectivity when complex **5** bearing a triphenylsilyl group at C3 and C3′ was used as the catalyst. Use of complex **6** bearing 1,2-diphenylethylenediamine as its diamine unit further improved the selectivity (**A**:**B** = 18:1) at the point of 24 h. The selectivity decreased with the reaction time because 1-octanol was preferentially consumed and the ratio of neopentyl alcohol in unreacted alcohols became large. This suggested that complex **6** could differentiate *n*-octanol and neopentyl alcohol efficiently at the initial stage of the reaction. Thus, it was expected that high regioselectivity would be realized, if 2,2-dimethylated 1,*n*-diols are used as substrates.

Along this line, oxidation of 2,2-dimethyl-1,4-butanediol and 2,2-dimethyl-1,5-pentanediol was next examined (Scheme 6). Although oxidation with complexes **4** and **5** showed modest selectivity, the oxidation with complex **6** showed high regioselectivity as expected [**A**:**B** = 22:1 (*n* = 1), 15:1 (*n* = 2)].

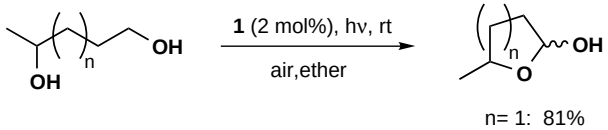
Typical experimental procedures are exemplified by the oxidation of hexane-1,5-diol with complex **1** and by the oxidation of 2,2-dimethylpentane-1,5-diol with complex **6**.

Hexane-1,5-diol (11.8 mg, 0.1 mmol) was weighed into a round-bottomed flask (Pyrex) followed by addition of 1-bromonaphthalene (0.1 mmol) as an internal standard and diethyl ether (1 ml). An aliquot was taken out of the flask and concentrated, and then submitted to ^{1}H NMR (400 MHz) analysis to adjust the molar ratio of the components. To the solution was added **1** (1.4 mg, 2 μmol) and the mixture was stirred under air for 24 h under irradiation with a halogen lamp (15 V, 150 W) at room temperature. The reaction mixture was concentrated under slightly reduced pressure and analyzed by ^{1}H NMR to calculate the yield of the lactols. The formation of 5-oxohexan-1-ol was not observed.

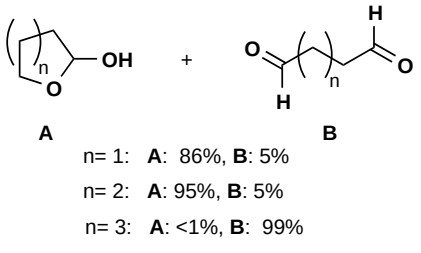
2,2-Dimethylpentane-1,5-diol (13.2 mg, 0.1 mmol) and pentamethylbenzene (14.8 mg, 0.1 mmol, an internal standard) were dissolved in $CDCl_3$ (1 ml). An aliquot was taken out of the flask and submitted to ^{1}H NMR (400 MHz) analysis to adjust the molar ratio of the components. To the solution was added complex **6** (6.0 mg, 5 μmol) and the mixture was stirred under air for

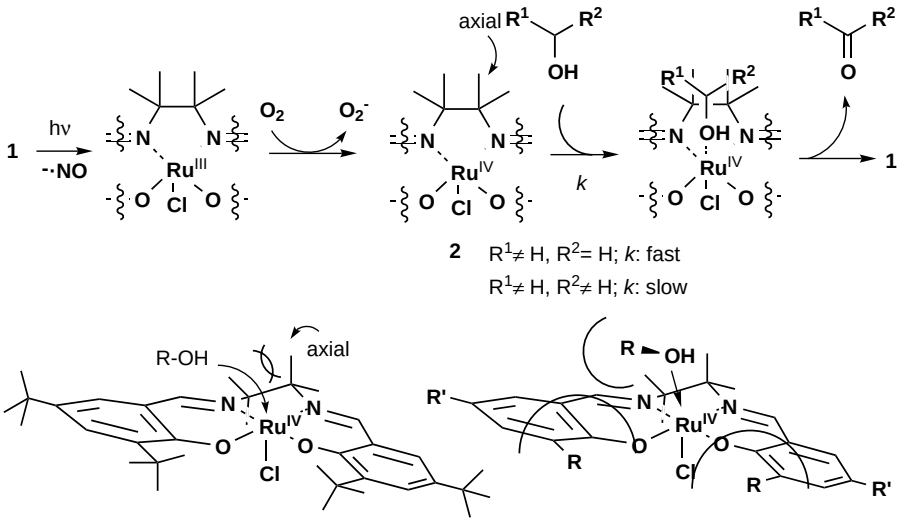


Scheme 2.

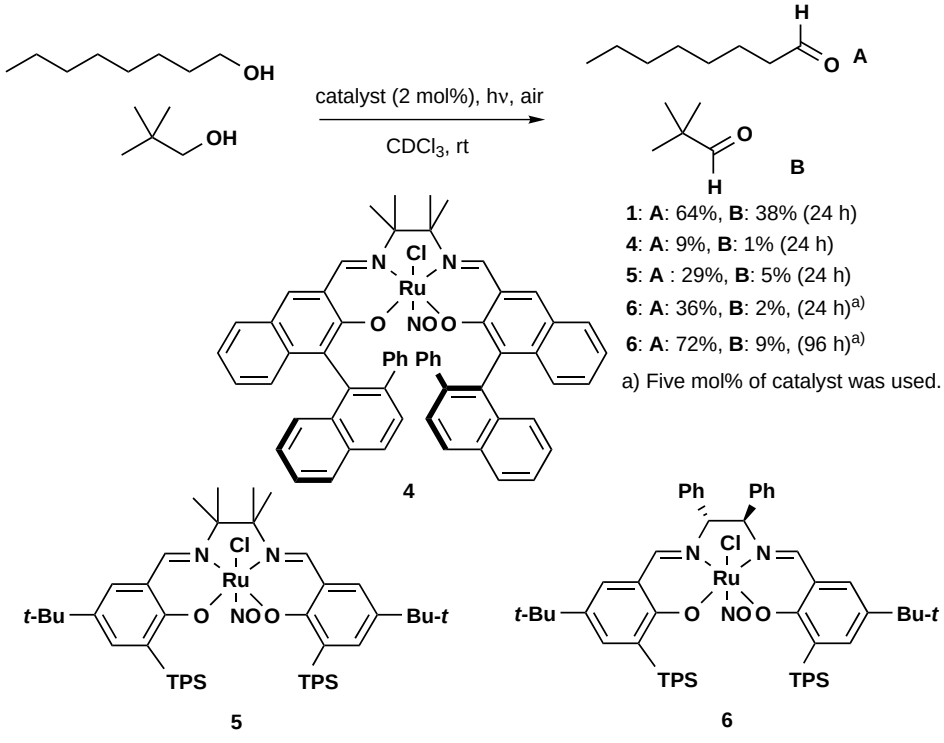


Scheme 3.

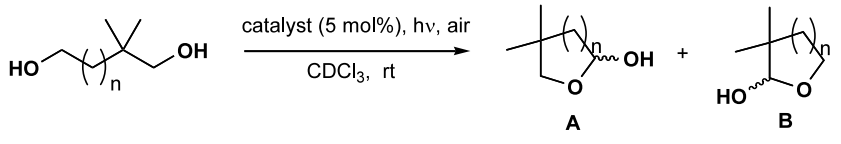




Scheme 4.



Scheme 5.



n = 1
4: **A** : **B** = 7.6 : 1 (24 h, 29%)
5: **A** : **B** = 6.0 : 1 (24 h, 98%)
6: **A** : **B** = 22 : 1 (36 h, 98%)[a)]

n = 2
4: **A** : **B** = 5.7 : 1 (24 h, 60%)
5: **A** : **B** = 3.9 : 1 (24 h,100%)
6: **A** : **B** = 15 : 1 (36 h, 98%)[a)]

a) Five mol% of catalyst was used.

Scheme 6.

36 h under irradiation with a halogen-lamp at room temperature. ^{1}H NMR analysis demonstrated that the diol was completely consumed and lactols (**A** and **B**) were formed in the ratio of 15:1. No formation of lactone was detected.

In conclusion, we were able to demonstrate that well-designed (ON)Ru(salen) complexes catalyzed regioselective oxidation of diols to the corresponding lactols under aerobic conditions. Further study is under way in our laboratory.

References

1. Miyata, A.; Murakami, M.; Irie, R.; Katsuki, T. *Tetrahedron Lett*. **2001**, *42*, 7067–7070.
2. For another example of aerobic chemoselective oxidation of primary alcohols, see: Hanyu, A.; TakeZawa, E.; Sakaguchi, S.; Ishii, Y. *Tetrahedron Lett*. **1998**, *39*, 5557–5560.
3. For other aerobic oxidation of alcohols, see: (a) Matsumoto, M.; Ito, S. *J. Chem. Soc., Chem. Commun*. **1981**, 907–908; (b) Matsumoto, M.; Watanabe, N. *J. Org. Chem*. **1984**, *49*, 3436–3437; (c) Yamada, T.; Mukaiyama, T. *Chem. Lett*. **1989**, 519–22; (d) Bäckvall, J.-E.; Chowdhury, R. L.; Karlsson, U. *J. Chem. Soc., Chem. Commun*. **1991**, 473–475; (e) Murahashi, S.-I.; Naota, T.; Hirai, N. *J. Org. Chem*. **1993**, *58*, 7318–7319; (f) Wang, G.-Z.; Andreasson, U.; Bäckvall, J.-E. *J. Chem. Soc., Chem. Commun*. **1994**, 1037–1038; (g) Rajendran, S.; Trivedi, D. C. *Synthesis* **1995**, 153–154; (h) Markó, I. E.; Giles, P. R.; Tsukazaki M.; Brown, S. M.; Urch, C. J. *Science* **1996**, 2044–2046; (i) Lenz, R.; Ley, S. V. *J. Chem. Soc., Perkin Trans. 1* **1997**, 3291–3292; (j) Markó, I. E.; Giles, P. R.; Tsukazaki, M.; Chellé-Regnaut, I.; Urch, C. J.; Brown, S. M. *J. Am. Chem. Soc*. **1997**, *119*, 12661–12662; (k) Kaneda, K.; Yamashita, T.; Matsushita, T.; Ebitani, K. *J. Org. Chem*. **1998**, *63*, 1750–1751; (l) Markó, I. E.; Gautier, A.; Chellé-Regnaut, I.; Giles P.-R.; Tsukazaki, M.; Urch, C. J.; Brown, S. M. *J. Org. Chem*. **1998**, *63*, 7576–7577; (m) Nishimura, T.; Onoue, T.; Ohe, K.; Uemura, S. *Tetrahedron Lett*. **1998**, *39*, 6011–6014; (n) Yamaguchi, K.; Mori, K.; Mizugaki, T.; Ebitani, K.; Kaneda, K. *J. Am. Chem. Soc*. **2000**, *122*, 7144–7145; (o) Lee, M.; Chang, S. *Tetrahedron Lett*. **2000**, *41*, 7507–7510; (p) ten Brink, G.-J.; Arends, I. W. C. E.; Sheldon, R. A. *Science* **2000**, *287*, 1636–1639; (q) Masutani, K.; Uchida, T.; Irie, R.; Katsuki, T. *Tetrahedron Lett*. **2000**, *41*, 5119–5123; (r) Döbler, C.; Mehltretter, G. M.; Sundermeier, U.; Eckert, M.; Militzer, H.-C.; Beller, M. *Tetrahedron Lett*. **2001**, *42*, 8447–8449; (s) Kakiuchi, N.; Maeda, Y.; Nishimura, T.; Uemura, S. *J. Org. Chem*. **2001**, *66*, 6620–6625; (t) Ben-Daniel, R.; Alsters, P.; Newmann, R. *J. Org. Chem*. **2001**, *66*, 8650–8653; (u) Dijksman, A.; Malino-González, A.; Payeras, A. M. i.; Arends, I. W. C. E.; Sheldon, R. A. *J. Am. Chem. Soc*. **2001**, *123*, 6826–6833; (v) Son, Y.-C.; Makwana, V. D.; Howeel, A. R.; Suib, S. L. *Angew. Chem., Int. Ed*. **2001**, *40*, 4280–4283; (w) Cechetto, A.; Fontana, F.; Minisci, F.; Recupero, F. *Tetrahedron Lett*. **2001**, *42*, 6651–6653; (x) Pagliano, M.; Ciriminna, R. *Tetrahedron Lett*. **2001**, *42*, 4511–4514; (y) Fernández, I.; Pedro, J. P.; Roselló, A. L.; Ruiz, R.; Castro, I.; Ottenwaelder, X.; Journaux, Y. *Eur. J. Org. Chem*. **2001**, 1235–1247; (z) Jensen, D. R.; Pugsey, J. S.; Sigman, M. S. *J. Am. Chem. Soc*. **2001**, *123*, 7475–7476; (aa) Ferreira, E. M.; Stoltz, B. M. *J. Am. Chem. Soc*. **2001**, *123*, 7725–7726.
4. Ley, S. V.; Madin, A. In *Comprehensive Organic Synthesis*; Trost, B. M.; Fleming, I., Eds.; Pergamon: Oxford, 1991; Vol. 7, pp. 305–327.
5. For high-yielding lactol synthesis, see: (a) Howell, S. C.; Ley, S. V.; Mahon, M.; Worthington, P. A. *J. Chem. Soc., Chem. Commun*. **1981**, 507–508; (b) Siedlecka, R.; Skarzewski, J.; Mlochowski, J. *Tetrahedron Lett*. **1990**, *31*, 2177–2180; (c) Corey, E. J.; Palani, A. *Tetrahedron Lett*. **1995**, *44*, 7945–7948; (d) Corey, E. J.; Palani, A. *Tetrahedron Lett*. **1995**, *36*, 3485–3488.