Catalysis Communications 15 (2011) 27–31

Contents lists available at SciVerse ScienceDirect

Catalysis Communications

journal homepage: www.elsevier.com/locate/catcom

Short Communication

Recyclable ionic liquid-bridged chiral dimeric salen Mn(III) complexes for oxidative kinetic resolution of racemic secondary alcohols

Chengyong Li [a], Jiangfeng Zhao [a], Rong Tan [a,*], Zhigang Peng [a], Rongchang Luo [a], Ming Peng [a], Donghong Yin [a,b,**]

[a] Institute of Fine Catalysis and Synthesis, Hunan Normal University, Changsha 410081, Hunan, China
[b] R & D Center, China Tobacco Hunan Industrial Corporation, NO.426 Laodong Road, Changsha, Hunan, 410014, China

ARTICLE INFO

Article history:
Received 26 January 2011
Received in revised form 19 July 2011
Accepted 8 August 2011
Available online 16 August 2011

Keywords:
Chiral dimeric salen Mn(III) complexes
Ionic liquids (ILs)
Catalysis
Secondary alcohols
Oxidative kinetic resolution

ABSTRACT

Novel chiral dimeric salen Mn(III) complexes bridged with N,N-dialkylimidazolium ionic liquids (ILs) at the C-5 position of the salicylaldehyde moieties were designed and synthesized. The ILs-bridged complexes presented excellent enantioselectivity and catalytic activity in the oxidative kinetic resolution of α-methyl benzyl alcohol, using diacetoxyiodobenzene as oxidant. The complexes combined the high catalytic efficiency of the active centers and the special solubility of the ILs, thus exhibiting notable efficacy of oxidative kinetic resolution and facile recovery from the reaction system by changing the solvent.

1. Introduction

Optically active secondary alcohols are useful chiral auxiliaries and intermediates in the pharmaceutical, agrochemical, and fine chemical industries [1]. The oxidative kinetic resolution (OKR) of racemic secondary alcohols is an efficient method to obtain chiral secondary alcohols and their variants [2]. During the last 10 years, significant progress in nonenzymatic catalytic methods, such as those based on sparteine-Pd(II) complexes [3,4] and on several iridium or ruthenium complexes [5,6], had been designed for the OKR of racemic secondary alcohols. Recently, homogeneous chiral salen Mn(III) complexes have been found to be effective catalysts for OKR [7,8], but the separation of the catalysts have remained difficult. To solve this issue, immobilization of the chiral salen Mn(III) complexes onto solid supports have been attempted. This strategy produces recyclable catalysts for the OKR of racemic secondary alcohols [9–12]. Unfortunately, the low accessibility of the substrates often causes mass transfer limitations, and thereby reduces catalytic activity. Recently, ionic liquids (ILs) bonded to the chiral salen Mn(III) complex have been found to enhance catalysts efficiency and recovery [13,14]. Thus, immobilization of the complex using ILs might provide a means to develop reusable catalysts with high activity.

Herein, ILs with imidazolium were used as the bridge to bond covalently at the C-5 position of two salicylaldehyde moieties. Novel IL-bridged chiral dimeric salen Mn(III) complexes were synthesized. The special ionophilicity and polarity of the IL moiety played positive roles in increasing the enantiomeric excess (ee) and the efficacy of kinetic resolution (k_{rel}) in the OKR of racemic secondary alcohols. Moreover, the IL-bridged dimeric salen Mn(III) complexes were readily recovered by simple precipitation in n-hexane and efficiently reused.

2. Experimental

2.1. Materials

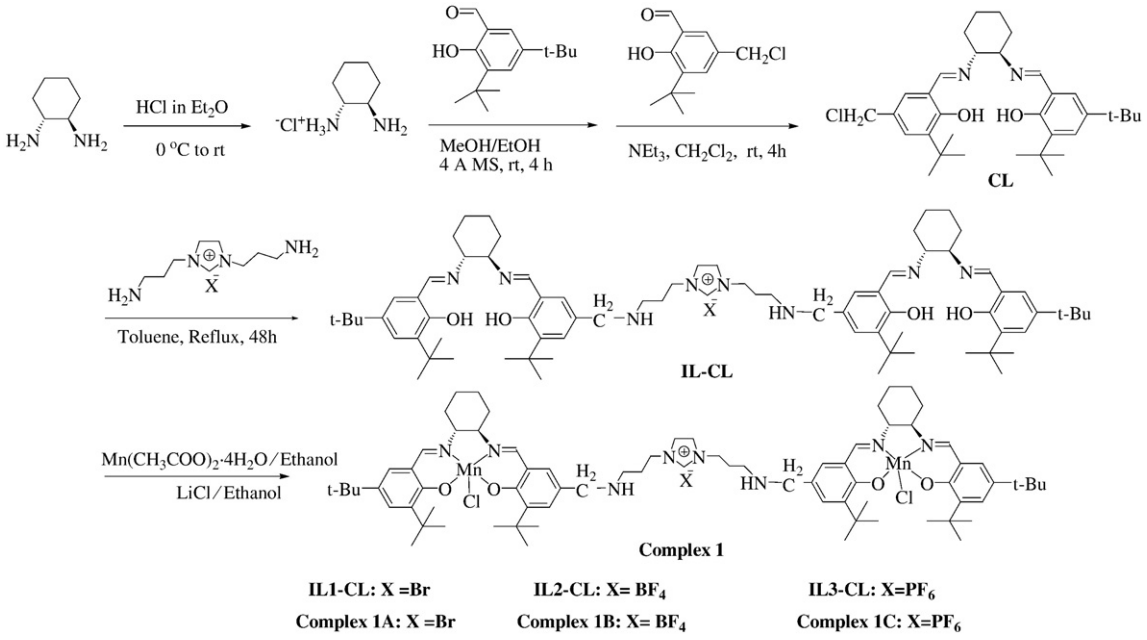
L(+)-Tartaric acid, 1,2-diaminocyclohexane, 3-bromopropylamine hydrobromide, diacetoxyiodobenzene ($PhI(OAc)_2$) and 1-methylimidazole were purchased from Acros. 2-*tert*-Butyl phenol was purchased from Alfa Aesar. All the racemic secondary alcohols used in the present study were prepared by the reduction of the corresponding ketones with $NaBH_4$. Other commercially available chemicals were obtained from local suppliers. (*R*,*R*)-1,2-diaminocyclohexane mono (hydrogen chloride) was prepared according to a previously described procedures [15].

2.2. Preparation of IL-bridged chiral dimeric salen Mn(III) complexes of **1A**, **1B** and **1C**

Synthesis of the complexes of **1A**, **1B,** and **1C** are presented in Scheme 1. The synthesis and identification of the IL-bridged salen Mn (III) complex **1A** and its corresponding intermediates are presented in detail in the supplementary information. A strategy to bridge covalently chiral ligand (CL) with various IL moieties to prepare IL-bridged salen ligands was designed (Scheme 1). The dimeric salen Mn(III) complexes

* Corresponding author.
** Corresponding author. Tel.: +86 731 8872576; fax: +86 731 8872531.
E-mail addresses: yiyangtanrong@126.com (R. Tan), yindh@hunnu.edu.cn (D. Yin).

1566-7367/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.catcom.2011.08.009



Scheme 1. Synthesis of the *IL*-bridged chiral dimeric salen Mn(III) complexes of **1A, 1B** and **1C.**

of **1A**, **1B**, and **1C** with (*R,R*)-configuration were obtained by reaction of IL-bridged salen ligands with $Mn(CH_3COO)_2$ followed by air oxidation. LiCl was added just before air oxidation.

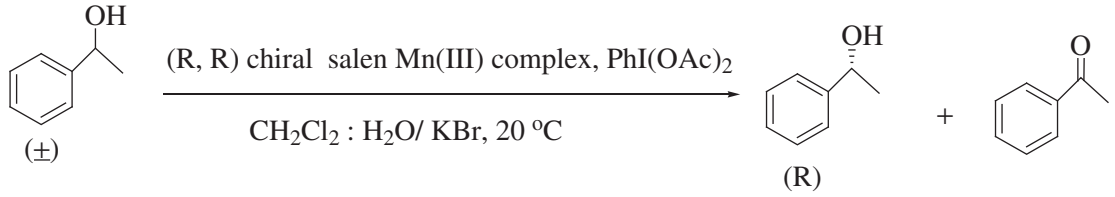
2.3. Characterization methods

Fourier transform infrared (FT-IR) spectra were obtained at 400–4000 cm^{-1} region on an AVATAR 370 Thermo Nicolet spectrophotometer, using KBr pellets. UV–vis spectra were obtained on a UV–vis Agilent 8453 spectrophotometer at 200–800 nm. The Mn ion content was measured by the complexometric method with ethylenediamine tetraacetic acid, as described previously [16]. Reaction products were analyzed on an Agilent Technologies 6890 N gas chromatograph equipped with a 19091 G-B213 chiral capillary column (30 m × 0.32 mm × 0.25 μm) and a flame ionization detector.

2.4. Typical procedure for the OKR of racemic secondary alcohols

The racemic secondary alcohols (0.25 mmol), catalyst (0.0025 mmol, 1 mol% of substrate, based on monomeric unit of the complex), KBr

Table 1
Results of the OKR of α-methyl benzyl alcohol over various catalysts.[a]



Entry	Catalyst	Run times	Conversion[b] (%)	ee[b] (%)	k_{rel}[c]	TON[d]
1	/	/	60	0	/	/
2	Complex **1A**	Fresh	62	99	20.0	62
3		2nd	62	99	20.0	62
4		3rd	62	98	17.2	62
5		4th	62	98	17.2	62
6		5th	62	98	17.2	62
7	Complex **1B**	Fresh	63	99	18.3	63
8		2nd	63	99	18.3	63
9		5th	62	98	17.2	62
10	Complex **1C**	Fresh	62	98	17.2	62
11		2nd	62	98	17.2	62
12		5th	62	98	17.2	62
13	Complex **2**	Fresh	59	56	3.8	59
14	Complex **3**	Fresh	64	97	13.2	64

[a] Reaction conditions: Catalyst (1 mol% of substrate, based on monomeric unit of the complex), KBr (6 mol% of substrate), α-methyl benzyl alcohol (0.25 mmol), $PhI(OAc)_2$ (0.175 mmol), H_2O/CH_2Cl_2 (1 ml/0.5 ml), 0.5 h, 20 °C.
[b] Determined by GC.
[c] k_{rel} value is calculated by the expression of $\ln[(1-C)(1-ee)]/\ln[(1-C)(1+ee)]$, where C is the conversion of the secondary alcohol and ee is the enantiomeric excess of the secondary alcohol.
[d] Turnover number (TON): total moles of oxidized alcohol per mole of active metal centre.

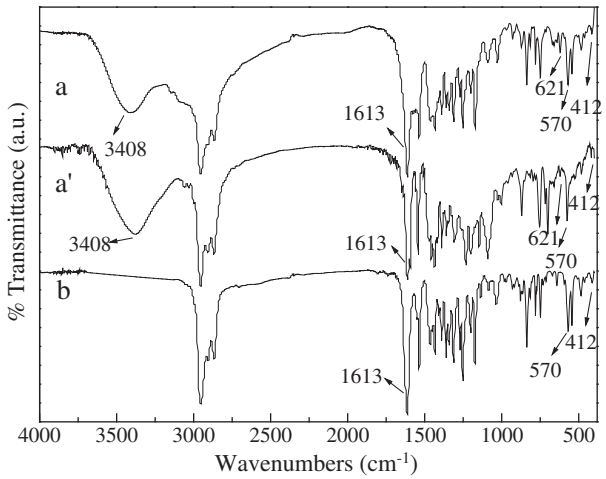


Fig. 1. FT-IR spectra of the fresh complex **1A** (a), complex **1A** after 5th reuse (a′), and the fresh complex **3** (b).

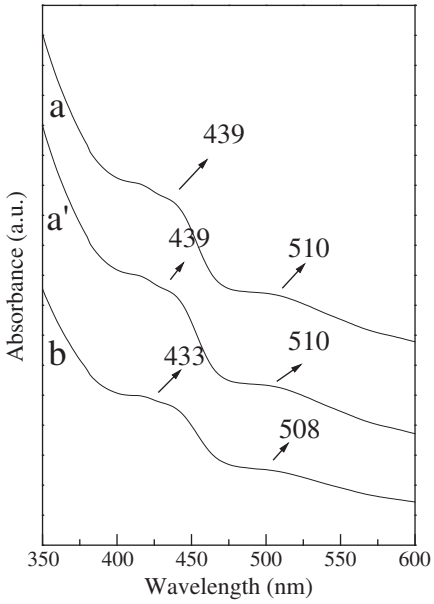


Fig. 2. UV–vis spectra of the fresh complex **1A** (a), complex **1A** after 5th reuse (a′), and the fresh complex **3** (b).

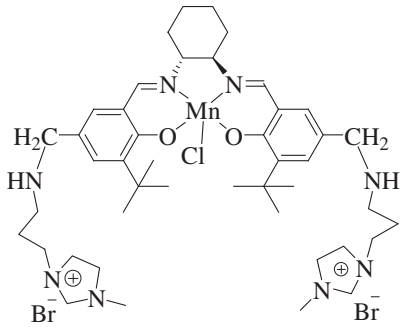
(0.015 mmol, 1.78 g), CH_2Cl_2 (0.5 ml), and H_2O (1.0 ml) were stirred for 10 min at room temperature. Afterward, $PhI(OAc)_2$ (0.175 mmol, 0.056 g) was added. Gas chromatography was employed to monitor the progress of the reaction. After complete reaction, hexane was added to extract the product. The catalyst was separated from the reaction mixture as a precipitate and subsequently used without further purification.

3. Results and discussion

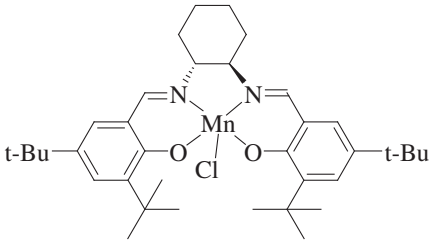
3.1. Catalytic activity of the chiral salen Mn(III) complexes for the OKR of α-methyl benzyl alcohol

The chiral salen Mn(III) complex with *(R,R)*-configuration could selectively oxidize the *(S)*-secondary alcohol to produce the corresponding ketone, leaving secondary alcohol enriched with *(R)*-configuration isomer [8]. Table 1 summarizes the catalytic activity and enantioselectivity of the chiral salen Mn(III) complexes in the OKR of α-methyl benzyl alcohol. No enantioselectivity was observed without the catalyst (entry 1). This confirms the necessity of the chiral salen Mn(III) complex in the OKR of α-methyl benzyl alcohol (Table 1). The complex **1A** produced higher ee (>99%) of *(R)*-α-methyl benzyl alcohol, with a k_{rel} value (20.0) higher than that of the neat chiral salen Mn(III) complex **3** (k_{rel} = 13.2) (entry 2 *vs.* 14). The enhanced ee and k_{rel} values may be due to the readily solubility of **1A** in the solvent of dichloromethane, and the synergy of the two catalytic active sites of **1A** [17]. Changing the counter ion of the IL moiety from Br^- to BF_4^- (*1B*) and PF_6^- (**1C**) did not improve the ee of the reaction and the k_{rel} value (entries 2, 7, and 10). To investigate the steric hindrance caused by the substituents of the chiral salen ligand on the catalytic performance, the chiral salen Mn(III) complex **2** (Chart 1), prepared according to our previous method [14] was also used as a catalyst for the OKR. This complex was functionalized by the IL 1-propylamine-3-methylimidazolium bromide at the C-5, 5′ positions of the salicylaldehyde moiety of the salen ligand. Complex **2** was less effective than complex **1A**, as evidenced by the low ee and k_{rel} (entry 13 *vs.* 2). This may be due to the lower steric hindrance of the $–CH_2$-IL substituent group in complex **2**. Therefore, *tert*-Butyl group substituents, due to the bulk steric hindrance and strong electron-donating abilities at C-5′, improve the enantioselectivity [7]. In addition, bromide salts such as additives were also absolutely crucial for fast and highly enantioselective OKR, since the bromide ion could activate the Mn (III)-salen complex through forming an active dibromo-Mn(V) species [18]. Low conversion and poor enantioselectivity resulted when the additive was not used even over the complexes of **1A**, **1B** and **1C.** The results were presented in the supplementary information (see Table S1 and Table S2).

The interesting soluble feature of the **1A**, **1B,** and **1C** complexes depend on their inherent tendency to precipitate in n-hexane, since the IL moiety has selective solubility in the solvent. After one catalytic run, the catalysts could be easily separated from the reaction mixture by the addition of hexane, and reused for the subsequent catalytic runs by adding fresh reactants. The IL-bridged salen Mn(III) complexes with various anions could be reused at least five times without significant loss of activity and enantioselectivity (Table 1). The maintenance of catalytic



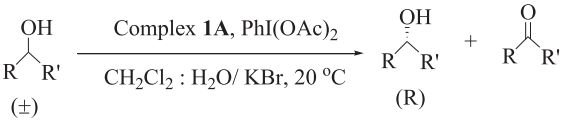
Complex **2**

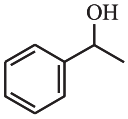
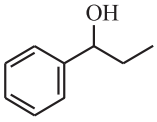
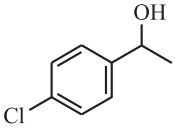
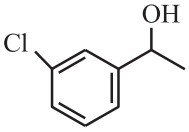
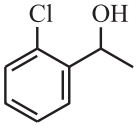
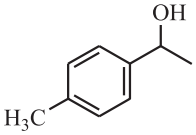
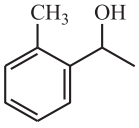
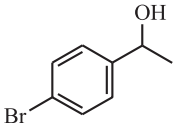
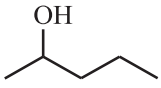
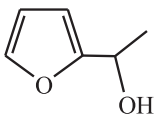


Complex **3**

Chart 1. Structure of the *IL*-functionalized chiral salen Mn(III) complex **2**, and the neat chiral salen Mn(III) complex **3.**

Table 2
Results of the OKR of various secondary alcohols over the complex **1A**.[a]



Entry	Substrate	Conversion (%)[b]	ee (%)[b]	k_{rel}[c]	TON[d]
1		62	>99	20.0	62
2		54	27	2.03	54
3		65	94	10.0	65
4		47	32	2.85	47
5		32	5	1.30	32
6		60	93	13.8	60
7		14	8	3.16	14
8		63	92	10.3	63
9		61	95	14.4	61
10		trace	/	/	/

[a] Same as in Table 1.
[b] Same as in Table 1.
[c] Same as in Table 1.
[d] Same as in Table 1.

performances for the recovered complexes relate to the unique solubility and the structural stability of the complexes. The Mn content in the supernatant after reaction was further detected by the complexometric method, and no Mn leaching was found in the supernatant. The results suggest that **1A**, **1B,** and **1C** complexes were stable toward the organic solvent, water, and oxidizing agents during the OKR of α-methyl benzyl alcohol. The FT-IR and UV–vis absorption characteristics of fresh and recovered **1A** and **3** complexes are presented in Figs. 1 and 2. No significant changes in the FT-IR and UV–vis spectra of the **1A** complex were observed even after 5 cycles of reuse. Furthermore, the main spectroscopic characteristics of **1A** complex resembled those of **3**, indicating that the active site in **1A** was intact during IL bonding.

3.2. Catalytic activity for the OKR of various secondary alcohols

Table 2 summarizes the OKR of other secondary alcohols over **1A**. The steric hindrance around the hydroxyl group of the substrates played a significant role in the overall efficiency of the kinetic resolution. Extension of the alkyl chain of the substrate (from R′ = CH_3 to R′ = CH_2CH_3) resulted in the sharp decrease of the ee value from 99% to 27%, and of the k_{rel} value from 20.0 to 2.03 (entry 1 *vs.* 2). α-methylbenzyl alcohols substituted at the *ortho*-position underwent relatively poor OKR compared with the *para*-substituted counterpart. The substituents –Cl, –CH_3, and –Br at the *para*-position of α-methylbenzyl alcohol produced high ee values (94%, 93%, and 92%, respectively), and k_{rel} values of 10.0, 13.8, and 10.3, respectively (entries 3, 6, and 8, respectively, Table 2). While, if α-methyl-*o*-chlorobenzyl alcohol and α-methyl-*o*-methylbenzyl alcohol were used as the substrates, only 5% and 8% of the enantioselectivity, with 1.30 and 3.16 k_{rel} values (entries 5 and 7) were obtained, respectively. The substituent of Cl at the *meta*-position of α-methylbenzyl alcohol was also tested. The enantioselectivity (32%) and k_{rel} value (2.85) were lower than those of the *para*-substituted counterpart but higher than those of the *ortho*-substituted counterpart (entry 4). The results suggested that the bulk steric hindrance caused by the substituted groups prevented the hydroxyl group in the substrate to approach the catalytic metal center of **1A**, and therefore decreased the ee and k_{rel} values. Furthermore, the complex **1A** was effective for the OKR of 2-pentanol, where 95% ee with 14.4 k_{rel} value could be obtained (entry 9). However, the chiral salen Mn (III) complex **1A** was inactive for heterocyclic compounds such as 2-furylethanol (entry 10).

4. Conclusions

The novel IL-bridged chiral dimeric salen Mn(III) complexes were synthesized and used as catalysts for the OKR of racemic secondary alcohols. The IL moiety conferred tunable solubility and improved catalytic activity of the complexes. High chiral purity (ee >99%) and k_{rel} value were achieved for the OKR of α-methylbenzyl alcohol over 1 mol% of the catalysts for 0.5 h. The complexes were easily recycled for five successive catalytic runs. The observations suggest that the complexes are promising chiral catalysts for the OKR of secondary alcohols.

Acknowledgements

The project was financial supported by the National Natural Science Foundation of China (Grant Nos. 20973057 and 21003044) and the Natural Science Foundation of Hunan Province (10JJ6028).

Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.catcom.2011.08.009.

References

[1] M. Wills, Angew. Chem. Int. Ed. 47 (2008) 4264–4267.
[2] W. Sun, H. Wang, C. Xia, J. Li, P. Zhao, Angew. Chem. Int. Ed. 42 (2003) 1042–1044.
[3] E.M. Ferreira, B.M. Stoltz, J. Am. Chem. Soc. 123 (2001) 7725–7726.
[4] D.R. Jensen, J.S. Pugsley, M.S. Sigman, J. Am. Chem. Soc. 123 (2001) 7475–7476.
[5] Y. Li, X. Zhang, Z. Dong, W. Shen, G. Chen, J. Gao, Org. Lett. 8 (2006) 5565–5567.

[6] K. Masutani, T. Uchida, R. Irie, T. Katsuki, Tetrahedron Lett. 41 (2000) 5119–5123.
[7] Z. Li, Z. Tang, X. Hu, C. Xia, Chem. Eur. J. 11 (2005) 1210–1216.
[8] K. Pathak, I. Ahmed, S.H.R. Abdi, R.I. Kureshy, N.H. Khan, R.V. Jasra, J. Mol. Catal. A: Chem. 274 (2007) 120–126.
[9] A.R. Silva, V. Budarin, J.H. Clark, B. de Castro, C. Freire, Carbon 43 (2005) 2096–2105.
[10] R.I. Kureshy, S. Singh, N.H. Khan, S.H.R. Abdi, I. Ahmed, A. Bhatt, R.V. Jasra, Catal. Lett. 107 (2006) 127–130.
[11] S. Sahoo, P. Kumar, F. Lefebvre, S.B. Halligudi, Tetrahedron Lett. 49 (2008) 4865–4868.
[12] S. Sahoo, P. Kumar, F. Lefebvre, S.B. Halligudi, Appl. Catal., A 354 (2009) 17–25.
[13] R. Tan, D. Yin, N. Yu, Y. Jin, H. Zhao, D. Yin, J. Catal. 255 (2008) 287–295.
[14] R. Tan, D. Yin, N. Yu, H. Zhao, D. Yin, J. Catal. 263 (2009) 284–291.
[15] M. Holbach, X. Zheng, C. Burd, C.W. Jones, M. Weck, J. Org. Chem. 71 (2006) 2903–2906.
[16] T. Zhou, E. Wang, W. Lu, Analytical Chemistry Section of Hangzhou University, The Handbook of Analytical Chemistry, second ed., Chemical Industry Press, Beijing, 1997, p. 559.
[17] R.I. Kureshy, I. Ahmed, K. Pathak, N.H. Khan, S.H.R. Abdi, J. Prathap, R.V. Jasra, Chirality 19 (2007) 352–357.
[18] M.K. Brown, M.M. Blewett, J.R. Colombe, E.J. Corey, J. Am. Chem. Soc. 132 (2010) 11165–11170.