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Article

Organotellurium catalysis-enabled utilization of molecular oxygen as oxidant for oxidative deoximation reactions under solvent-free conditions

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ABSTRACT

Catalyzed by commercially available $(PhTe)_2$, molecular oxygen could be utilized as the mild, cheap and safe oxidant for oxidative deoximation reactions under solvent-free conditions. As the first report on organotellurium-catalyzed deoximation reaction, this work not only provides an efficient deoximation method, but also discloses new features of tellurium catalyst different from those of the organoselenium catalysts.

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1. Introduction

Chalcogen elements, such as S, Se and Te, have extensive application scopes and their compounds are important intermediates in organic synthesis, medicinal chemistry, biochemistry and materials science for the unique chemical and biological activities [1–4]. Recently, the catalytic activities of organoselenium compounds in oxidation reactions have drawn much attention [5–10]. In comparison with S-O, Se-O bond is even weaker to allow the oxygen transferring into another molecule. Thus, organoselenium compounds can serve as good oxygen carrier catalysts in a variety of reaction processes [11–16]. However, in many cases of the organoselenium-catalyzed reactions, generations of diselenides caused by the over reduction of hypervalent organoselenium species are unavoidable [17]. Because diselenides are stable compounds difficult to be directly re-oxidized by molecular oxygen under the general reaction conditions, strong chemical oxidants are excessively employed to restrain their generation so that the catalyst deactivation can be avoided [18–20]. Addition of iron salt as co-catalyst could promote the aerobic oxidation of diselenides into hypervalent organoselenium species, so that the Se/Fe-co-catalyzed oxidation reactions could utilize molecular oxygen as the terminal oxidant [21], but introducing transition metal components into the catalyst systems might bring new issues, such as the increased catalyst cost, waste generation and the transition metal residues that might limit the application scope of the products. In comparison with the recently booming progresses of organoselenium catalysis [5–21], organotellurium-catalyzed reaction was not well-documented yet [22–25]. Recently, we found that, owing to the lower Te-Te bond energy (149 kJ/mol vs. 192 kJ/mol of Se-Se) [26], ditellurides are even more active than diselenides, so that the $(PhTe)_2$-catalyzed oxidation reactions could utilize molecular oxygen (O_2) as the mild, cheap and safe oxidant. This finding should be the beginning of the investigation on organotellurium catalysis, which is interesting and deserve to explore for potential industrial application value. Herein, we wish to report our findings.

2. Materials and methods

2.1. General methods

Reagents were purchased from reagent merchant with their purities more than 98% and were directly used as received.

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Solvents were analytical pure (AR) and directly used without any special treatment. Melting points were measured by WRS-2A digital instrument. IR spectra were measured on Bruker Tensor 27 Infrared spectrometer. NMR spectra were recorded on a Bruker Avance 600/400 instrument (600 or 400 MHz for ^{1}H NMR) using $CDCl_3$ as the solvent and Me_4Si as the internal standard. Chemical shifts for ^{1}H NMR were referred to internal Me_4Si (0 ppm) and *J*-values were shown in Hz.

2.2. General procedure for the deoximation reactions

To a 15 mL reaction tube, 1 mmol of ketoximes (**1**) and 0.025 mmol of $(PhTe)_2$ were added. The tube was then equipped with an O_2 balloon and was heated at 60 °C for 24 h. The mixture was separated by preparative thin-layer chromatography (eluent: petroleum/EtOAc = 15/1) to produce the related ketones (**2**). The characterization data and NMR spectra were given in Supplementary data.

3. Results and discussion

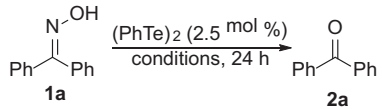
3.1. Reaction condition optimizations

During our continuous investigations on green catalysis science and technologies [27–30], we recently focused on the oxidative deoximation reaction because of the great significances of this transformation in fine chemical production, as well as the total synthesis of natural products [31,32]. Thus, in this work, commercially available $(PhTe)_2$ was tested to catalyze the oxidative deoximation reaction, which, at present stage, usually requires chemical reagents generating a lot of solid waste [33], explosive oxidants [34,35], halogen- or nitro-contained solvents or additives [36], or precious metal catalysts [37]. By using organoselenium catalysts, the reaction occurred under relatively green conditions, but strong oxidants such as H_2O_2 or transition metal co-catalysts were used to avoid the Se catalyst deactivation [21,34].

In this work, benzophenone oxime **1a** was initially chosen as the model substrate and it was heated with 2.5 mol% of $(PhTe)_2$ catalyst in MeCN using air as the oxidant. Catalytic amount of H_2O_2 (15 mol %) was introduced to convert $(PhTe)_2$ into the more active PhTe(O)OH species and the desired ketone **2a** was produced in 70% yield (Table 1, entry 1). Without H_2O_2, the yield of **2a** decreased to 48% (Table 1, entry 2). It was then found that O_2 was a better oxidant, giving **2a** in 95% yield even in the absence of H_2O_2 (Table 1, entry 3). Solvent screenings demonstrated that the reaction occurred smoothly in both EtOH and H_2O (Table 1, entries 4,5), but solvent-free conditions were more favorable from the practical viewpoint, affording **2a** in 93% yield (Table 1, entry 6).

Parallel experiments showed that 60 °C, as we initially employed, should be the preferable reaction temperature (Table 1, entries 6 vs. 7, 8). Reducing the catalyst amount to 1 mol%, **2a** was generated in 90% yield (Table 1, entry 9). The product yield decreased to 88% and 86% in the reactions of **1a** with 0.5 mol% or 0.1 mol% of $(PhTe)_2$ respectively (Table 1, entries 10, 11). Notably, the product yield of the reaction using 0.1 mol% of $(PhTe)_2$ catalyst was still higher than the same reaction catalyzed by 2.5 mol% of diselenide (86% in Table 1, entry 11 vs. 81% in Ref. [34]), showing that the Te catalyst was even more active than its Se analogues.

Table 1
Condition optimizations. [a]



1a **2a**

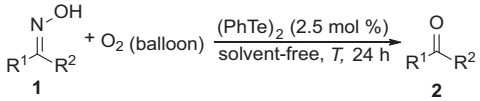
Entry	Conditions	cat./%	**2a** yield (%) [b]
1	H_2O_2 (15 mol %), MeCN, 60 °C, air	2.5	70
2	MeCN, 60 °C, air	2.5	48
3	MeCN, 60 °C, O_2	2.5	95
4	EtOH, 60 °C, O_2	2.5	92
5	H_2O, 60 °C, O_2	2.5	89
6	no solvent, 60 °C, O_2	2.5	93
7	no solvent, 40 °C, O_2	2.5	83
8	no solvent, 80 °C, O_2	2.5	87
9	no solvent, 60 °C, O_2	1	90
10	no solvent, 60 °C, O_2	0.5	88
11	no solvent, 60 °C, O_2	0.1	86

[a] 1 mmol of **1a**, 0.025 mmol of $(PhTe)_2$ and 1 mL of solvent (or no solvent) were employed; The reaction was performed with a balloon charged with air or O_2.
[b] Isolated yields on the basis of **1a** amount.

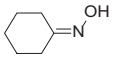
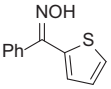
3.2. Extension of the substrate scopes

Under the optimized conditions (Table 1, entry 6), the reactions of a series of different oximes were tested to extend the substrate scopes of the method (Table 2). Introducing electron–donating groups onto the aryl ring resulted in decreased product yields (Table 2, entries 2, 3 vs. 1), while the electron-deficient substrate **1d** could produce the desired ketone **2d** in slightly enhanced yield (Table 2, entries 4 vs. 1). Reaction of acetophenone oxime **1e** led to acetophenone **2e** in 53% yield (Table 2, entry 5). The decreased product yield was probably due to its volatility that caused the weight loss in separation steps. Other acetophenone oximes **1f**–**k** led to

Table 2
Application scope examinations. [a]



1 **2**

Entry	**1**: R^1, R^2	*T* (°C)	**2**: yield (%) [b]
1	**1a**: Ph, Ph	60	**2a**: 93
2	**1b**: 4-MeC_6H_4, 4-MeC_6H_4	60	**2b**: 84
3	**1c**: 4-$MeOC_6H_4$, 4-$MeOC_6H_4$	60	**2c**: 70
4	**1d**: 4-FC_6H_4, 4-FC_6H_4	60	**2d**: 94
5	**1e**: Ph, Me	60	**2e**: 56[c]
6	**1f**: 4-MeC_6H_4, Me	60	**2f**: 85; 87 [d], 83 [d], 78 [d], 77 [d]
7	**1g**: 3-MeC_6H_4, Me	60	**2g**: 84
8	**1h**: 4-ClC_6H_4, Me	60	**2h**: 82
9	**1i**: 3-ClC_6H_4, Me	60	**2i**: 80
10	**1j**: 2-ClC_6H_4, Me	60	**2j**: 72
11	**1k**: 4-$NO_2C_6H_4$, Me	60	**2k**: 82
12	**1l**: Ph, *n*-C_3H_7	60	**2l**: 54
13	**1m**: Ph, *n*-C_4H_9	60	no reaction
14		80	**2m**: 65
15	**1n**: Ph, *n*-C_6H_{13}	80	no reaction
16		100	**2n**: 60 (86)
17	**1o**: *n*-C_6H_{13}, Me	60	**2o**: (73) [e]
18	**1p**: 	60	**2p**: (56) [e]
19		60	no reaction
20		100	**2q**: 5 (80)
21	**1q**: 	120	**2q**: 26 (85)
22	**1r**: 	100	**2r**: 31 (60)

[a] 1 mmol of **1** and 0.025 mmol of $(PhTe)_2$ were employed.
[b] Isolated yields based on oximes **1** without special instruction; values in parenthesis were the yields based on converted oximes **1**.
[c] Diminished yield due to product volatility.
[d] Yields for the 10 mmol-scale reactions with the catalyst used for the first to fourth time respectively.
[e] GC yield.

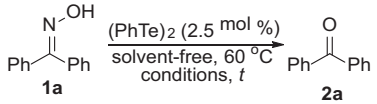
the related ketones **2f–k** in good yields (Table 2, entries 6–11). Notably, the organotellurium catalyst is robust to be recycled and reused. In the 10 mmol-scale reaction of **1f**, ketone **2f** was obtained in 87% yield with fresh $(PhTe)_2$ catalyst. The product was separated by distillation under vacuum, while the residues containing Te catalytic species could be reused as catalyst for the next turn of reaction, giving **2f** in 83% yield. The catalyst could be recycled and reused for at least three times to produce **2f** in good yields (Table 2, entry 6).

Bearing a bulky alkyl, (*E*)-1-phenylbutan-1-one oxime **1l** was less reactive, and produced 1-phenylbutan-1-one **2l** in decreased yield (Table 2, entry 12). The substrate reactivity decreased with the growing alkyl chain: The reaction of **1m** produced **2m** in 65% yield at 80 °C (Table 2, entries 14 vs. 13), while for **1n**, even higher reaction temperature was crucial (Table 2, entries 16 vs. 15). The reaction of aliphatic (*E*)-octan-2-one oxime led to octan-2-one in 73% yield (Table 2, entry 17). Cyclic ketone oximes, such as **1p–q**, were unfavorable substrates, and their reactions produced the related ketones in decreased yields even at high reaction temperature (Table 2, entries 18–21). These phenomena indicated that the deoximation process was remarkably affected by the steric hindrances of substrate. The Te-catalyzed reaction showed some degree of tolerance to heterocycles and substrate **1r** could produce the related ketone **2r** at 100 °C (Table 2, entry 22), but it was not applicable for aldoximes, and the reaction of benzaldehyde oxime led to PhCN and the Beckmann rearrangement product $PhC(O)NH_2$ in 67% and 33% GC yield respectively, other than the desired benzaldehyde product.

3.3. Reaction mechanism studies

The mechanism of this interesting organotellurium-catalyzed reaction was our next concern. Control experiments were performed to get sufficient information for mechanism study (Table 3). The reaction under N_2 protection led to **2a** in only 8% yield, indicating that O_2 was a crucial oxidant for this transformation (Table 3, entry 1). Although H_2O_2 was an efficient oxidant in many organoselenium-catalyzed reactions, the use of it instead of O_2 still resulted in a dramatically decreased **2a** yield at 18% (Table 3, entry 2) and this result demonstrated that the reaction might occurred through a completely different mechanism. Addition of azodiisobutyronitrile (AIBN) as the free-radical initiator obviously accelerated the reaction and produced **2a** in 85% yield within 6 h, whereas, the parallel reaction without AIBN led to **2a** in only 12% yield within the same reaction time (Table 3, entries 3 vs. 4). Moreover, addition of 2,2,6,6-tetramethylpiperidine-1-oxyl (TEMPO) as a free-radical scavenger restrained the reaction, and **2a** was generated in only 23% yield (Table 3, entry 5). Previously, it was found that $Yb(OTf)_3$ as a Lewis acid could activate carbonyls in Se-catalyzed reaction occurred via a nucleophilic attack step [34], but in this reaction, it was ineffective and did not enhance the **2a** yield (Table 3, entries 6, 7) or accelerate the reaction (Table 3, entries 8 vs. 4). The above experimental results (Table 3, entries 3–7) clearly revealed that the Te-catalyzed deoximation proceeded through a free-radical mechanism other than the reported ionic reaction steps.

Table 3
Control reactions. [a]



Entry	conditions	*t* (h)	**2a** yield (%) [b]
1	N_2	24	8
2	H_2O_2 (100 mol %), N_2	24	18
3	AIBN (100 mol %), O_2	6	85
4	O_2	6	12
5	TEMPO (100 mol %), O_2	24	23
6	$Yb(OTf)_3$ (1 mol %), O_2	24	92
7	$Yb(OTf)_3$ (1 mol %), Air	24	35
8	$Yb(OTf)_3$ (1 mol %), O_2	6	10

[a] Without special instruction, 1 mmol of **1a**, 0.025 mmol of $(PhTe)_2$ and 1 mL of solvent (or no solvent) were employed.
[b] Isolated yields on the basis of **1a** amount.

The catalytic Te species during the reaction processes were investigated by X-ray photoelectron spectroscopy (XPS) analysis. As shown in Fig. 1a, $(PhTe)_2$ was completely oxidized into the Te (IV) species such as PhTe(O)OH after 24 h of reaction. In the same sample, hypervalent nitrogen species such as NO_3^- was also detected (see Fig. S1 online), indicating that nitrogen moiety of the substrate was sufficiently oxidized under O_2 atmosphere. Heating $(PhTe)_2$ in air for 0.5 h, Te (IV) species began to emerge, while Te (II), which might attribute to PhTeOTePh, was the major Te species (Fig. 1b). Te(IV) ratio increased to 35% in the treated sample with O_2 as a stronger oxidant (Fig. 1c). Interestingly, $(PhTe)_2$ was completely converted into the hyper-valent Te (IV) species after being heated with the oxime **1a** under N_2 protection (Fig. 1d), indicating that the Te species was so reactive that it could be oxidized by the oxygen-containing substrates even without any additional oxidant.

Based on the above experimental results as well as the literature reports, a plausible mechanism was supposed (Scheme 1). As indicated in XPS spectra (Fig. 1), $(PhTe)_2$ could be oxidized by O_2 to generate intermediate **3** as the Te(II) species. Thermocleavage of the weak Te-O bond in **3** led to PhTeO and PhTe free-radicals **4** and **5** and the later could be oxidized to the former one by O_2. Further oxidation of **4** by O_2 led to the Te (IV) free-radical **6**. The free radical addition of **6** with substrate **1** produced **7** as the reaction intermediate. In this step, substrates with large steric hindrances were unfavorable and higher reaction temperature was required (Table 2, entries 13–20).

Decomposition of **7** led to the product **2** and by-product nitrosyl hydride (HNO) as well as the catalytic species **4** to restart the major catalysis circle A (Scheme 1) [21,34]. Under O_2 atmosphere, HNO could be sufficiently oxidized into hyper valent nitrogen species, which was detected in XPS spectrum (see Fig. S1 online). Moreover, it was also possible for **4** to directly react with **1** and generated

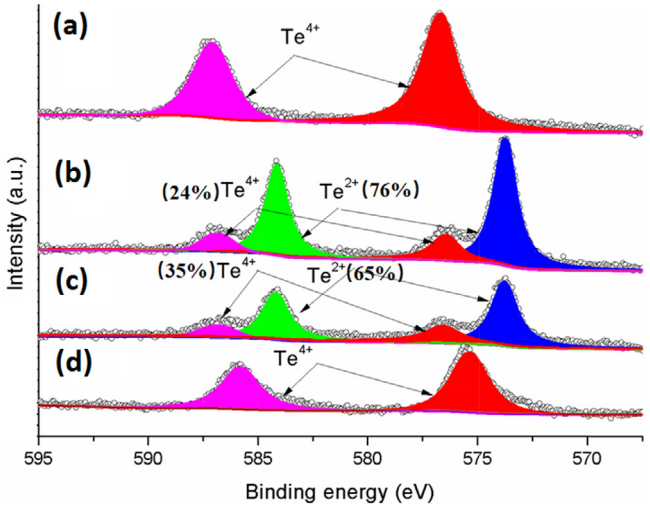
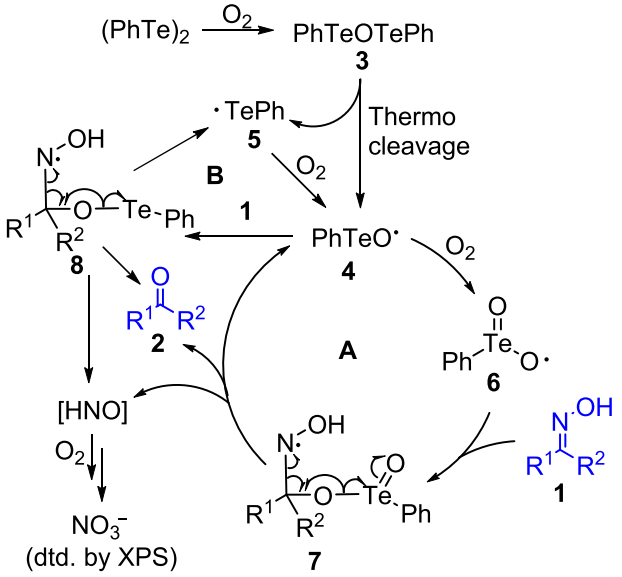


Fig. 1. (Color online) XPS studies of the Te species: (a) sample after a standard reaction; (b, c) heating $(PhTe)_2$ with air (image b) or O_2 (image c) at 60 °C for 0.5 h; (d) heating **1a** with catalytic amount of $(PhTe)_2$ (2.5 mol %) at 60 °C for 1 h under N_2 protection.



Scheme 1. (Color online) Possible mechanisms.

another intermediate **8**, which might decompose into the product **2**, the by-product HNO, as well as the Te species **5**. Oxidation of **5** by O_2 afforded **4** and restarted the sub-catalysis circle B (Scheme 1).

4. Conclusions

In conclusion, this work reported a more efficient method of oxidative deoximation, which might be very useful in practical applications for the environmental-friendly processes free of solvent and using O_2 as the cheap, safe and clean oxidant, as well as the commercially available and recyclable Te catalyst. Besides, as the first example of organotellurium catalysis, it has disclosed several new features versus the previously reported organoselenium-catalyzed reactions, which are listed as follows:

(1) Because of the weak bond energy, organotellurium catalysts are even more sensitive than organoselenium catalysts, allowing the use of reduced amount of catalyst but giving enhanced product yields.
(2) Te species are easier to be oxidized, so that in the catalyzed oxidation reactions, use of the strong oxidants, such as H_2O_2 etc, are not necessary, affording the opportunity to utilize molecular oxygen as the mild oxidant.
(3) Different from organoselenium catalysis, organotellurium-catalyzed reactions prefer to occur via the free-radical mechanisms other than the ionic reactions.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

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Author contributions

Xin Deng, Hongen Cao and Chao Chen performed the experiments; Hongwei Zhou guided Xin Deng performing partial of the experiment, revised the manuscript and gave suggestions on mechanism study (especially on the characterization of the nitrogen species after reaction); Lei Yu raised the idea of Te catalysis, guided Xin Deng, Hongen Cao and Chao Chen performing experiments and wrote the paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scib.2019.07.007.

References

[1] Wang M, Jiang X. Sulfur–sulfur bond construction. Topics Curr Chem 2018;376:14.
[2] Feng M, Tang B, Liang SH, et al. Sulfur containing scaffolds in drugs: synthesis and application in medicinal chemistry. Curr Top Med Chem 2016;16:1200–16.
[3] Liu M, Li Y, Yu L, et al. Visible light-promoted, iodine-catalyzed selenoalkoxylation of olefins with diselenides and alcohols in the presence of hydrogen peroxide/air oxidant: an efficient access to α-alkoxyl selenides. Sci China Chem 2018;61:294–9.
[4] Vieira AA, Azeredo JB, Godoi M, et al. Catalytic chalcogenylation under greener conditions: a solvent-free sulfur- and seleno-functionalization of olefins via I_2/DMSO oxidant system. J Org Chem 2015;80:2120–7.
[5] Guo R, Liao L, Zhao X. Electrophilic selenium catalysis with electrophilic N-F reagents as the oxidants. Molecules 2017;22:835.
[6] Breder A, Ortgies S. Recent developments in sulfur- and selenium-catalyzed oxidative and isohypsic functionalization reactions of alkenes. Tetrahedron Lett 2015;56:2843–52.
[7] Młochowski J, Wójtowicz-Młochowska H. Developments in synthetic application of selenium(IV) oxide and organoselenium compounds as oxygen donors and oxygen-transfer agents. Molecules 2015;20:10205.
[8] Santoro S, Azeredo JB, Nascimento V, et al. The green side of the moon: ecofriendly aspects of organoselenium chemistry. RSC Adv 2014;4:31521–35.
[9] Santi C, Santoro S, Battistelli B. Organoselenium compounds as catalysts in nature and laboratory. Curr Org Chem 2010;14:2442–62.
[10] Freudendahl DM, Santoro S, Shahzad SA, et al. Green chemistry with selenium reagents: development of efficient catalytic reactions. Angew Chem Int Ed 2009;48:8409–11.
[11] Depken C, Krätzschmar F, Rieger R, et al. Photocatalytic aerobic phosphatation of alkenes. Angew Chem Int Ed 2018;57:2459–63.
[12] Liu X, Liang Y, Ji J, et al. Chiral selenide-catalyzed enantioselective allylic reaction and intermolecular difunctionalization of alkenes: efficient construction of C-SCF_3 stereogenic molecules. J Am Chem Soc 2018;140:4782–6.
[13] Luo J, Cao Q, Cao X, et al. Selenide-catalyzed enantioselective synthesis of trifluoromethylthiolated tetrahydronaphthalenes by merging desymmetrization and trifluoromethylthiolation. Nat Commun 2018;9:527.
[14] Guo R, Huang J, Zhao X. Organoselenium-catalyzed oxidative allylic fluorination with electrophilic N-F reagent. ACS Catal 2018;8:926–30.
[15] Ortgies S, Rieger R, Rode K, et al. Mechanistic and synthetic investigations on the dual selenium-π-acid/photoredox catalysis in the context of the aerobic dehydrogenative lactonization of alkenoic acids. ACS Catal 2017;7:7578–86.
[16] Jin W, Zheng P, Wong WT, et al. Efficient selenium-catalyzed selective C(sp^3)–H oxidation of benzylpyridines with molecular oxygen. Adv Synth Catal 2017;359:1588–93.
[17] Yu L, Wang J, Chen T, et al. Access to cyclohexane-1,2-diol through the diphenyldiselenide catalyzed oxidation of cyclohexene by hydrogen peroxide. Chin J Org Chem 2013;33:1096–9.
[18] Wang T, Jing X, Chen C, et al. Organoselenium-catalyzed oxidative C=C bond cleavage: a relatively green oxidation of alkenes into carbonyl compounds with hydrogen peroxide. J Org Chem 2017;82:9342–9.
[19] Yu L, Bai Z, Zhang X, et al. Organoselenium-catalyzed selectivity-switchable oxidation of β-ionone. Catal Sci Technol 2016;6:1804–9.
[20] Yu L, Ye J, Zhang X, et al. Recyclable $(PhSe)_2$-catalyzed selective oxidation of isatin by H_2O_2: a practical and waste-free access to isatoic anhydride under mild and neutral conditions. Catal Sci Technol 2015;5:4830–8.
[21] Chen C, Zhang X, Cao H, et al. Iron-enabled utilization of air as the terminal oxidant leading to aerobic oxidative deoximation by organoselenium catalysis. Adv Synth Catal 2019;361:603–10.
[22] Alberto EE, Muller LM, Detty MR. Rate accelerations of bromination reactions with NaBr and H_2O_2 via the addition of catalytic quantities of diaryl ditellurides. Organometallics 2014;33:5571–81.
[23] Oba M, Okada Y, Nishyama K, et al. Aerobic photooxidation of phosphite esters using diorganotelluride catalysts. Org Lett 2009;11:1879–81.

[24] Oba M, Tanaka K, Nishiyama K, et al. Aerobic oxidation of thiols to disulfides catalyzed by diaryl tellurides under photosensitized conditions. J Org Chem 2011;76:4173–7.
[25] Okada Y, Oba M, Arai A, et al. Diorganotelluride-catalyzed oxidation of silanes to silanols under atmospheric oxygen. Inorg Chem 2010;49:383–5.
[26] Housecroft CE, Sharpe AG. Inorganic Chemistry. fourth ed. Pearson Education Ltd.; 2012.
[27] Yu L, Qian R, Deng X, et al. Calcium-catalyzed reactions of element-H bonds. Sci Bull 2018;63:1010–6.
[28] Cao H, Zhu B, Yang Y, et al. Recent advances on controllable and selective catalytic oxidation of cyclohexene. Chin J Catal 2018;39:899–907.
[29] Zhang D, Wei Z, Yu L. Easily fabricated and recyclable Pd&Cu@Al catalyst for gram-scale phosphine-free heck reactions with high TON. Sci Bull 2017;62:1325–30.
[30] Zhang H, Han M, Yang C, et al. Gram-scale preparation of dialkylideneacetones through $Ca(OH)_2$-catalyzed Claisen-Schmidt condensation in dilute aqueous EtOH. Chin Chem Lett 2019;30:263–5.
[31] Zheng Y, Wu A, Ke Y, et al. Recent advances on deoximation: from stoichiometric reaction to catalytic reaction. Chin Chem Lett 2019;30:937–41.
[32] Zhang G, Wen X, Wang Y, et al. Recent advances in oxidative deoximation. Prog Chem 2012;24:361–9.
[33] Pradhan PK, Dey S, Jaisankar P, et al. Fe-HCl: an efficient reagent for deprotection of oximes as well as selective oxidative hydrolysis of nitroalkenes and nitroalkanes to ketones. Synth Commun 2005;35:913–22.
[34] Jing X, Yuan D, Yu L. Green and practical oxidative deoximation of oximes to ketones or aldehydes with hydrogen peroxide/air by organoselenium catalysis. Adv Synth Catal 2017;359:1194–201.
[35] Chu S, Cao H, Chen T, et al. Selenium-doped carbon: an unexpected efficient solid acid catalyst for Beckmann rearrangement of ethyl 2-(2-aminothiazole-4-yl)-2-hydroxyiminoacetate. Catal Commun 2019;129:105730.
[36] Zhang G, Wen X, Wang Y, et al. Sodium nitrite catalyzed aerobic oxidative deoximation under mild conditions. J Org Chem 2011;76:4665–8.
[37] Isart C, Bastida D, Burés J, et al. Gold(III) complexes catalyze deoximations/transoximations at neutral pH. Angew Chem Int Ed 2011;50:3275–9.

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