A highly efficient protocol for regioselective ring-opening of epoxides with alcohols, water, acetic acid, and acetic anhydride catalyzed by SbF₃

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ABSTRACT
SbF₃ as an efficient catalyst has been used for regioselective alcoholysis, acetolysis and hydrolysis of epoxides to the corresponding β-alkoxy, β-acetoxy alcohols, and 1,2-diols in high to excellent yields. This study also represents a convenient synthesis of vic-diacetates from ring-opening of epoxides with acetic anhydride.

GRAPHICAL ABSTRACT

Introduction
The ring strain and polarization of carbon-oxygen bonds make epoxides versatile synthetic intermediates in organic synthesis.¹⁻³ Ring-opening of epoxides occurs under various conditions, however, the convenient protocols are achieved in the presence of Lewis acids. In this situation, reaction of epoxides with alcohols, acetic acid, and water affords β-alkoxy, β-acetoxy alcohols, and 1,2-diols. DDQ,⁴ FeCl₃,⁵ Fe(TFA)₃,⁶ FeCl₃·6H₂O/SiO₂,⁷ FeCl₃·6H₂O/polystyrene,⁸ Amberlyst-15,⁹ TiCl₃(OTf) and TiO(TFA)₂,¹⁰ CAN,¹¹ Ce(OTf)₃,¹² graphite oxide,¹³ Al(OTf)₃,¹⁴ Cp₂ZrCl₂,¹⁵ ZrO₂,¹⁶ ZrO(OTf)₂,¹⁷ InCl₃,¹⁸ (NH₄)₃[CeW₁₂O₴₃],¹⁹ AlPW₁₂O₴₀,²⁰ Sn(tpp)(OTf)₂,²¹ Sn(tpp)(BF₄)₂,²² and silica sulfuric acid²³ are some of catalysts which have been used for nucleophilic ring-opening of epoxides.

The ring-opening of epoxides with water leading to the preparation of 1,2-diols is one of the most convenient reactions, and the subsequent acetylation of these diols provides an efficient means for protection and preparation of vic-diacetates.²⁴ A literature review shows that this transformation has been achieved by the reaction of epoxides and acetic anhydride in the presence of ZrO(OTf)₂,²⁵ phosphomolybdic acid,²⁶ NaBH₄,²⁷ HY zeolite,²⁸ Bu₃P,²⁹ LiClO₄,³⁰ Er(OTf)₃,³¹ Bu₄NCl,³² Bu₄NOAc,³³ (TBA)₄PFeW₁₁O₃₉·3H₂O,³⁴ and (NH₄)₃PMO₁₂O₴₀.³⁵ Although most of the reported protocols are efficient and useful, however, the drawbacks such as operational difficulty (refs: 17, 29 and 31), unavailability and high cost of reagents (17, 25, 28, 31 and 35), limited scope of the utilized epoxides and nucleophiles (28 and 31) and the prolonged reaction times (28 and 29) put some restrictions to use the methods for any practical applications. In line with the outlined strategies and in continuation of our research program directed to the synthetic transformation of epoxides,³⁶⁻⁴² herein, we wish to introduce SbF₃ for convenient ring-opening of epoxides with primary, secondary, and tertiary alcohols, acetic acid, water, and acetic anhydride to afford β-alkoxy, β-acetoxy alcohols, and 1,2-diols as well as vic-diacetates in high to excellent yields (Scheme 1).

Results and discussion
Antimony trifluoride, SbF₃, is sometimes called Swart’s reagent. A literature review shows that as well as some industrial applications,⁴³ this reagent is usually used as fluorinating agent

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in inorganic and organofluorine chemistry.\textsuperscript{44,45} Although, the application of SbF$_3$ for fast and efficient reduction of nitro compounds with NaBH$_4$ was successfully reported,\textsuperscript{46} however, the catalytic activity of SbF$_3$ in organic reactions was not frequently documented. Thus, introduction of new synthetic methodologies catalyzed by SbF$_3$ and our interest towards preparation of \( \beta \)-alkoxy, \( \beta \)-acetoxy alcohols and 1,2-diols as key intermediates, encouraged us to study alcoholysis, acetolysis and hydrolysis of epoxides with primary, secondary, and tertiary alcohols, acetic acid and water in the presence of SbF$_3$.

Reaction conditions were primarily optimized by performing the alcoholysis of styrene oxide in MeOH and in the presence of SbF$_3$. Different molar equivalents of the reactants as well as performing the reaction at room temperature or reflux were examined in the typical experiment. The obtained results showed that using 0.1 mmol of SbF$_3$ per 1 mmol of the epoxide at reflux was sufficient to convert styrene oxide to 2-methoxy-2-phenylethanol within 8 min in high regioselectivity and yield (Scheme 1, \( \alpha \)-attacked). Encouraged by this success and in order to study ring-opening of styrene oxide in different alcholic media, we performed alcoholysis of the model compound in refluxing EtOH, \( n \)-PrOH, \( i \)-PrOH, and \( t \)-BuOH using 0.1 mmol SbF$_3$. The summarized results in Table 1 show that the reaction of styrene oxide with primary, secondary, and tertiary alcohols was carried out successfully within 15–60 min and 2-alkoxy-2-phenylethanol were obtained in high regioselectivity. The results also show that the bulk hindrance of alcoholic solvent decreases the rate enhancement of ring-opening reaction.

At the next, the reaction of other epoxides having different ring substitutions such as allyl, phenyl and isopropyl glycidyl ethers, 1,2-epoxyoctane and cyclohexene oxide was carried out in MeOH, EtOH, \( n \)-PrOH, \( i \)-PrOH and \( t \)-BuOH using 0.1 mmol SbF$_3$ at reflux. Table 1 show that all reactions took place successfully within 5–60 min to afford alkoxide alcohols in high regioselectivity through solvolysis of the epoxide rings from less hindered position (Scheme 1, \( \beta \)-attacked). In the case of cyclohexene oxide, the ring-opening reactions encountered with the formation of racemic \( \beta \)-alkoxy cyclohexanols in high yields.

The influence of SbF$_3$ (0.1 mmol) in acetylation and hydrolysis of epoxides was also studied by ring-opening of aryl and alkyl substituted epoxides with acetic acid and water. Investigation of the results reveals that acetylation of epoxides took place in refluxing acetic acid as the same manner of alcoholysis reactions. It means that styrene oxide as an aryl substituted epoxide exclusively produces 2-acetoxy-2-phenylethanol (\( \alpha \)-attacked), and alkyl substituted epoxides gives the corresponding acetoxy alcohols via \( \beta \)-attacking of acetic acid (Scheme 1). In the case of cyclohexene oxide, the racemic \( \beta \)-acetoxy cyclohexanol was obtained as a sole product.

Further examination also showed that ring-opening of the utilized epoxides with water in a mixture of H$_2$O/CH$_3$CN (1.5:0.5 mL) as the solvents of choice and in the presence of SbF$_3$ (0.1 mmol) provided a good synthetic method for hydrolysis of epoxides to the corresponding 1,2-diols. Table 1 shows that all acetylation and hydrolysis reactions were carried out within 10–40 min giving the products in 60–98% yields.

Direct preparation of \( \nu ic \)-diacetates from epoxides was another goal that has been successfully achieved by SbF$_3$. Optimization experiments showed that solvolysis of styrene oxide in refluxing Ac$_2$O and in the presence of 0.3 mmol SbF$_3$ took place efficiently to afford 1,2-diacetoxy-1-phenylethane in high yield. In the case of alkyl substituted epoxides, this transformation was also carried out perfectly using 0.3–0.4 mmol SbF$_3$ in acetic anhydride at reflux. The results of this investigation are illustrated in Table 2. As seen, \( \nu ic \)-diacetates were obtained in 80–95% yields when the reactions were taken place within 2 h.

Product analysis revealed that only one diastereomer with \( trans \) 1,2-diacetoxy groups was prepared by the reaction of cyclohexene oxide in acetic anhydride. Stereochemical assignment was achieved by: (i) comparison of the obtained \( ^1 \)H NMR spectrum with one of authentic sample reported in the literature,\textsuperscript{47} and (ii) hydrolysis of \( rac-trans \)-1,2-diacetoxy cyclohexane to white crystalline \( rac-trans \)-1,2-cyclohexanediol (mp 101–103°C, found: 101–104°C, lit.\textsuperscript{48}) (Scheme 2).

The usefulness of SbF$_3$ in nucleophilic ring-opening of epoxides was highlighted by a comparison of the obtained results for methanolysis of 2,3-epoxypropylphenyl ether and preparation of 1,2-diacetoxy-1-phenylethane from styrene oxide catalyzed by SbF$_3$ and other reported reagents (Tables 3 and 4). A case study shows that in viewpoints of availability and cheapness of the catalysts, selectivity and yield of products, SbF$_3$ shows a more or comparable efficiency towards the other reagents. In addition, the green aspects of SbF$_3$ are also considerable: this reagent, as a white solid compound, is stable under air atmosphere to afford its handling without any precaution. Because of good solubility in water, its work-up and removing from the reaction mixture is also carried out very easily.

Our experience in SbF$_3$-catalyzed ring opening of styrene oxide with MeOH also showed that under nonsolvolytic conditions, the reaction was not efficient and the progress of the reaction encountered with poor yield after 120 min (Scheme 3). This result revealed that the current protocol is useful only for nucleophiles that can be used as a solvent of choice.
Table 1. Alcoholysis, acetolysis, and hydrolysis of epoxides catalyzed by SbF$_3$.\(^a\)

| Entry | Epoxide | Product | ROH      | Time (min) | Yield (%)\(^b\) | Ref. |
|-------|---------|---------|----------|------------|-----------------|-----|
| 1     |         |         | MeOH     | 8          | 93              | 19,23 |
| 2     |         |         | EtOH     | 15         | 92              | 19   |
| 3     |         |         | n-PrOH   | 20         | 95              | 19,23 |
| 4     |         |         | i-PrOH   | 60         | 98              | 19,23 |
| 5     |         |         | t-BuOH   | 60         | 89              | 19   |
| 6     |         |         | AcOH     | 10         | 98              | 21   |
| 7     |         |         | H$_2$O/CH$_3$CN\(^c\) | 15 | 85              | 21,23 |
| 8     |         |         | MeOH     | 10         | 89              | 19,23 |
| 9     |         |         | EtOH     | 15         | 81              | 19   |
| 10    |         |         | n-PrOH   | 30         | 96              | 19,23 |
| 11    |         |         | i-PrOH   | 50         | 85              | 19,23 |
| 12    |         |         | t-BuOH   | 50         | 83              | 19,23 |
| 13    |         |         | AcOH     | 15         | 98              | 21   |
| 14    |         |         | H$_2$O/CH$_3$CN\(^c\) | 20 | 75              | 21,23 |
| 15    |         |         | MeOH     | 15         | 92              | 19,23 |
| 16    |         |         | EtOH     | 20         | 91              | 19   |
| 17    |         |         | n-PrOH   | 25         | 84              | 19,23 |
| 18    |         |         | i-PrOH   | 35         | 85              | 19,23 |
| 19    |         |         | t-BuOH   | 40         | 80              | 19,23 |
| 20    |         |         | AcOH     | 20         | 98              | 21   |
| 21    |         |         | H$_2$O/CH$_3$CN\(^c\) | 40 | 85              | 21,23 |
| 22    |         |         | MeOH     | 15         | 87              | 19,21 |
| 23    |         |         | EtOH     | 20         | 85              | 19,21 |
| 24    |         |         | n-PrOH   | 25         | 95              | 19,21 |
| 25    |         |         | i-PrOH   | 40         | 85              | 19,21 |
| 26    |         |         | t-BuOH   | 50         | 90              | 19,21 |
| 27    |         |         | AcOH     | 15         | 80              | 21   |
| 28    |         |         | H$_2$O/CH$_3$CN\(^c\) | 20 | 70              | 21   |
| 29    |         |         | MeOH     | 20         | 88              | 19,21 |
| 30    |         |         | EtOH     | 30         | 84              | 19,21 |
| 31    |         |         | n-PrOH   | 40         | 85              | 19,21 |
| 32    |         |         | i-PrOH   | 60         | 97              | 19,21 |
| 33    |         |         | t-BuOH   | 60         | 80              | 19,21 |
| 34    |         |         | AcOH     | 20         | 91              | 21   |
| 35    |         |         | H$_2$O/CH$_3$CN\(^c\) | 30 | 80              | 21   |
| 36    |         |         | MeOH     | 5          | 84              | 19,23 |
| 37    |         |         | EtOH     | 10         | 85              | 19   |
| 38    |         |         | n-PrOH   | 20         | 90              | 19,23 |
| 39    |         |         | i-PrOH   | 20         | 84              | 19   |
| 40    |         |         | t-BuOH   | 25         | 89              | 19   |
| 41    |         |         | AcOH     | 10         | 85              | 21   |
| 42    |         |         | H$_2$O/CH$_3$CN\(^c\) | 20 | 60              | 21,23 |

\(^a\)All reactions were carried out with a molar ratio of epoxide/SbF$_3$ (1:0.1) at reflux.

\(^b\)Yields refer to isolated pure products.

\(^c\)A mixture of H$_2$O/CH$_3$CN (1.5:0.5 mL) was used as a solvent.

In summary, we have shown that SbF$_3$ can be used as an efficient catalyst for nucleophilic ring-opening of epoxides with alcohols, acetic acid, water and acetic anhydride to afford β-alkoxy, β-acetoxy alcohols, 1,2-diols and vic-diacetates. All reactions were carried out with 0.1−0.4 mmol of SbF$_3$ to afford the products in high to excellent yields. The cheapness and availability of the catalyst, excellent regioselectivity, applicability to a wide range of epoxides, high yields and easy work-up procedure are the advantages which make SbF$_3$ a synthetically useful catalyst in nucleophilic ring-opening of various epoxides.

**Experimental**

**General**

All reagents and substrates were purchased in high purity from Merck Company and were used without further purification. FT−IR and $^1$H, $^{13}$C NMR spectra were recorded on Thermo Nicolet Nexus 670 and Bruker Avance 300 MHz spectrometers, respectively. The products were characterized by their FT−IR and $^1$H, $^{13}$C NMR spectra and compared with data reported in literature. All yields refer to isolated pure products. TLC was applied for the purity determination of the substrates, products and the reaction monitoring over silica gel 60 F$_{254}$ aluminum sheet. The Supplemental Materials file contains sample $^1$H and $^{13}$C NMR for some of the known products (Figures S 1−S 8)

**Alcoholysis, acetolysis and hydrolysis of epoxides catalyzed by SbF$_3$: A general procedure**

In a round-bottomed flask (15 mL) equipped with a magnetic stirrer and condenser, SbF$_3$ (0.1 mmol) was added to a solution of epoxide (1 mmol) in an appropriate alcohol, acetic acid (1.5 mL) or a mixture of H$_2$O/CH$_3$CN (1.5:0.5 mL). The
### Table 2. Conversion of epoxides to vic-diacetates catalyzed by SbF₃

| Entry | Epoxide | vic-Diacetate | SbF₃ (mmol) | Yield (%) | Ref. |
|-------|---------|---------------|-------------|-----------|------|
| 1     | ![Epoxide](image1.png) | ![Diacetate](image2.png) | 0.3         | 89        | 25,26 |
| 2     | ![Epoxide](image3.png) | ![Diacetate](image4.png) | 0.3         | 85        | 25,26 |
| 3     | ![Epoxide](image5.png) | ![Diacetate](image6.png) | 0.4         | 95        | 25,26 |
| 4     | ![Epoxide](image7.png) | ![Diacetate](image8.png) | 0.4         | 90        | 25,26 |
| 5     | ![Epoxide](image9.png) | ![Diacetate](image10.png) | 0.3         | 85        | 25,26 |
| 6     | ![Epoxide](image11.png) | ![Diacetate](image12.png) | 0.3         | 80        | 25,26 |
| 7     | ![Epoxide](image13.png) | ![Diacetate](image14.png) | 0.3         | 90        | 25,26 |
| 8     | ![Epoxide](image15.png) | ![Diacetate](image16.png) | 0.3         | 87        | 25,26 |

*a* All reactions were carried out with 1 mmol of epoxide in refluxing Ac₂O (1.0 mL) within 2 h.  
*b* Yields refer to isolated pure products.

### Scheme 2. Hydrolysis of trans-1,2,2-diacetoxycyclohexane to trans-1,2-cyclohexanediol.

### Table 3. Comparison of methanalysis of 2,3-epoxypropylphenyl ether catalyzed by SbF₃ and other reported reagents.

| Entry | Catalyst | Mol% | Condition | Time (min) | Yield (%) | Selectivity (%) | Ref. |
|-------|----------|------|-----------|------------|-----------|-----------------|------|
| 1     | SbF₃     | 10   | Reflux    | 15         | 92        | 100             | –    |
| 2     | Fe(TFA)₂ | 10   | Reflux    | 120        | 94        | 100             | 6    |
| 3     | TiCl₃(Tf) | 10   | Reflux    | 105        | 99        | 100             | 10   |
| 4     | TiO(TFA)₂ | 43   | Reflux    | 330        | 98        | 100             | 10   |
| 5     | Ge(Otf)₃ | 5    | Reflux    | 20         | 93        | 100             | 12   |
| 6     | ZrO(Otf)₂ | 0.75 | Reflux    | 20         | 99        | 100             | 17   |
| 7     | InCl₃     | 20   | 50 °C     | 540        | 74        | 100             | 18   |
| 8     | Amberlyst-15/sonication | 0.1 g | 24–28 °C | 50         | 95        | 97              | 9    |
| 9     | Graphite oxide | 0.01 g | r.t. | 120        | 72        | 100             | 13   |
| 10    | Al₂P₂W₁₆O₄₄ | 3    | r.t. | 15         | 94        | 100             | 20   |
| 11    | (NH₄)₂[CeW₁₀O₃₉] | 4    | Reflux | 10         | 95        | 100             | 19   |
| 12    | Sn(tpp)(OTf)₂ | 1.9   | Reflux | 5          | 99        | 100             | 21   |
Table 4. Comparison of the conversion of styrene oxide to 1,2-diacetoxy-1-phenylethane catalyzed by SbF$_3$ and other reported reagents.

| Entry | Catalyst | Mol% | Condition | Time (h) | Yield (%) | Ref. |
|-------|----------|------|-----------|----------|-----------|------|
| 1     | SbF$_3$  | 30   | Reflux    | 2        | 89        | –    |
| 2     | PMA      | 1    | r.t.      | 0.25     | 95        | 25   |
| 3     | PMA-SiO$_2$ | 5    | r.t.      | 0.08     | 98        | 25   |
| 4     | MS 4 Å   | 0.15 g | Reflux  | 2        | 90        | 26   |
| 5     | NaBH$_4$ | 20   | Reflux    | 1.5      | 96        | 27   |
| 6     | Bu$_4$NCl | 5    | Reflux    | 3        | 83        | 28   |
| 7     | HY Zeolite | 0.05 g | r.t.      | 12       | 90        | 29   |
| 8     | Bu$_3$P  | 10   | Reflux    | 24       | 98        | 31   |
| 9     | Er(OTf)$_3$ | 0.1 | r.t.      | 2        | 0         | 31   |
| 10    | Zr(OH)$_2$Cl | 0.75 | 50 °C  | 1 min    | 99        | 17   |
| 11    | LiClO$_4$ | 50   | r.t.      | 2–5      | 66        | 30   |
| 12    | (NH$_4$)$_2$PMO$_12$O$_40$ | 10 | r.t.    | 1        | 98        | 35   |

Scheme 3. SbF$_3$ –catalyzed ring-opening of styrene oxide with MeOH under nonsolvolytic conditions.

reaction mixture was stirred under reflux for the mentioned time in Table 1. After completion of the reaction, distilled water (5 mL) was added and the mixture was stirred for additional 5 min. The mixture was extracted with EtOAc (2 × 5 mL) and then dried over anhydrous sodium sulfate. The eluted product was concentrated under reduced pressure and then subjected to chromatography on a glass column (10 cm length, 0.5 cm diameter) of silica gel 60 (230–400 mesh) to give the pure product in excellent yield (60–98%, Table 1).

Conversion of epoxides to vic-diacetates catalyzed by SbF$_3$: A general procedure

In a round-bottomed flask (15 mL) equipped with a magnetic stirrer and condenser, SbF$_3$ (0.3–0.4 mmol) was added to a solution of epoxide (1 mmol) in acetic anhydride (1 mL). The reaction mixture was stirred under reflux for 2 h. After completion of the reaction, an aqueous solution of NaHCO$_3$ (5%, 5 mL) was added and the mixture was stirred for additional 5 min. The mixture was extracted with EtOAc (2 × 5 mL) and then dried over anhydrous sodium sulfate. The eluted product was concentrated under reduced pressure and then subjected to chromatography on a glass column (10 cm length, 0.5 cm diameter) of silica gel 60 (230–400 mesh) to give the pure product in excellent yield (80–95%, Table 2).

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References

1. Yudin, A. K. Aziridines and Epoxides in Organic Synthesis; Wiley: Weinheim, 2006.
2. Aggarwal, V. K.; Harvey, J. N.; Richardson, J. J. Am. Chem. Soc. 2002, 124, 5747–5756.
3. Sharghi, H.; Nasser, M. A.; Niknam, K. J. Org. Chem. 2001, 66, 7287–7293.
4. Iranpoor, N.; Mohammadpour Baltork, I. Tetrahedron Lett. 1990, 31, 735–738.
5. Iranpoor, N.; Salehi, P. Synthesis 1994, 1152–1154.
6. Iranpoor, N.; Adibi, H. Bull. Chem. Soc. Jpn. 2000, 73, 675–680.
7. Iranpoor, N.; Tarrian, T.; Movahedi, Z. Synthesis 1996, 1473–1476.
8. Yarapathi, R. V.; Malla Reddy, S.; Tammisetti, S. React. Funct. Polym. 2005, 64, 157–161.
9. Liu, Y. H.; Liu, Q. S.; Zhang, Z. H. J. Mol. Catal. A: Chem. 2008, 296, 42–46.
10. Iranpoor, N.; Zeynizadeh, B. Synth. Commun. 1999, 29, 1017–1024.
11. Iranpoor, N.; Mohammadpour Baltork, I. Synth. Commun. 1990, 20, 2789–2797.
12. Iranpoor, N.; Shekarriz, M.; Shiriny, F. Synth. Commun. 1998, 28, 347–366.
13. Mirza-Aghayan, M.; Alizadeh, M.; Molaei Tavana, M.; Bokhkherroub, R. Tetrahedron Lett. 2014, 55, 6694–6697.
14. Williams, D. B. G.; Lawton, M. Org. Biomol. Chem. 2005, 3, 3269–3272.
15. Kantam, M. L.; Aziz, K.; Jeyalakshmi, K.; Likhar, P. R. Catal. Lett. 2003, 89, 95–97.
16. Shameli, A.; Ghanbari, M. M. Trends Modern Chem. 2012, 3, 14–17.
17. Moghadam, M.; Mohammadpour-Baltork, I.; Tangestaninejad, S.; Mirkhani, V.; Shariati, L.; Babaghariani, M.; Zarea, M. J. Iran. Chem. Soc. 2009, 6, 789–799.
18. Kim, B. H.; Piao, F.; Lee, E. J.; Kim, J. S.; Jun, Y. M.; Lee, B. M. Bull Korean Chem. Soc. 2004, 25, 881–888.
19. Mirkhani, V.; Tangestaninejad, S.; Yazdollahi, B.; Alipanah, L. Tetrahedron 2003, 59, 8213–8218.
20. Firouzabadi, H.; Iranpoor, N.; Jafari, A.; Makarem, S. J. Mol. Catal. A: Chem. 2006, 250, 237–242.
21. Moghadam, M.; Tangestaninejad, S.; Mirkhani, V.; Shaibani, R. Tetrahedron 2004, 60, 6105–6111.
22. Moghadam, M.; Tangestaninejad, S.; Mirkhani, V.; Mohammadpoor-Baltork, I.; Toghavi, A. Catal. Commun. 2007, 8, 2087–2095.
23. Salehi, P.; Dabiri, M.; Zolfigol, M. A.; Bodaghi Fard, M. A. Phosphorus, Sulfur, Silicon Relat. Elem. 2004, 179, 1113–1121.
24. Greene, T. W.; Wuts, P. G. M. *Protective Groups in Organic Synthesis*, 4th ed.; Wiley: New York, 2006.
25. Zeynizadeh, B.; Sadighnia, L. *Bull. Korean Chem. Soc.* **2010**, *31*, 2644-2648.
26. Gilanizadeh, M.; Zeynizadeh, B. *Curr. Chem. Lett.* **2015**, *4*, 153–158.
27. Zeynizadeh, B.; Sadighnia, L. *Synth. Commun.* **2011**, *41*, 637–644.
28. Ramesh, P.; Niranjan Reddy, V. L.; Venugopal, D.; Subrahmanyan, M.; Venkateswarlu, Y. *Synth. Commun.* **2001**, *31*, 2599-2604.
29. Fan, R. H.; Hou, X. L. *Tetrahedron Lett.* **2003**, *44*, 4411-4413.
30. Azizi, N.; Mirmashhori, B.; Saidi, M. R. *Catal. Commun.* **2007**, *8*, 2198-2203.
31. Dalpozzo, R.; De Nino, A.; Nardi, M.; Russo, B.; Procopio, A. *Arkivoc* **2006**, VI, 67-73.
32. Fogassy, G.; Pinel, C.; Gelbard, G. *Catal. Commun.* **2009**, *10*, 557-560.
33. Abdur Rahman, M.; Fraser-Reid, B. *J. Am. Chem. Soc.* **1985**, *107*, 5576-5578.
34. Yadollahi, B.; Kabiri Esfahani, F. *Chem. Lett.* **2007**, *36*, 676–677.
35. Das, B.; Saidi Reddy, V.; Tehseen, F. *Tetrahedron Lett.* **2006**, *47*, 6865-6868.
36. Zeynizadeh, B.; Baradarani, M. M.; Eisavi, R. *Phosphorus, Sulfur, Silicon Relat. Elem.* **2011**, *186*, 2208-2215.
37. Eisavi, R.; Zeynizadeh, B.; Baradarani, M. M. *Phosphorus, Sulfur, Silicon Relat. Elem.* **2011**, *186*, 1902-1909.
38. Eisavi, R.; Zeynizadeh, B.; Baradarani, M. M. *Bull. Korean Chem. Soc.* **2011**, *32*, 630-634.
39. Zeynizadeh, B.; Sadighnia, L. *Bull. Korean Chem. Soc.* **2010**, *31*, 2644-2648.
40. Zeynizadeh, B.; Yeghaneh, S. *Phosphorus, Sulfur, Silicon Relat. Elem.* **2009**, *184*, 362-368.
41. Zeynizadeh, B.; Sadighnia, L. *Phosphorus, Sulfur, Silicon Relat. Elem.* **2008**, *183*, 2274-2279.
42. Zeynizadeh, B.; Yeghaneh, S. *Phosphorus, Sulfur, Silicon Relat. Elem.* **2008**, *183*, 2280-2286.
43. Grund, S. C.; Hanusch, K.; Breunig, H. J.; Wolf, H. U. Antimony and antimony compounds. In *Ullmann’s Encyclopedia of Industrial Chemistry*; Wiley-VCH: Weinheim, 2006.
44. Mahmood, T.; Lindahl, C. B. Fluorine compounds, inorganic, antimony. In *Kirk-Othmer Encyclopedia of Chemical Technology*, 4th ed.; Wiley-VCH: New York, 2004.
45. Swarts, F. *Bull. Acad. Roy. Belg.* **1892**, *3*, 474.
46. Zeynizadeh, B.; Ghasemi, H. J. *Chem. Res.* **2006**, *542*, 542-544.
47. Detry, J.; Rosenbaum, T.; Lütz, S.; Hahn, D.; Jaeger, K. E.; Müller, M.; Eggert, T. *Appl. Microbiol. Biotechnol.* **2006**, *72*, 1107–1116.
48. Aldrich Handbook - a Catalog of Fine Chemicals and Laboratory Equipment 2012–2014, http://www.sigmaaldrich.com/chemistry/aldrich-chemistry/aldrich-handbook.html.