

Natrolite zeolite: A natural and reusable catalyst for one-pot synthesis of α -aminophosphonates under solvent-free conditions

Siavash Bahari^a and S. Mohammad Sajadi^{b,*}

This paper is dedicated to the Soran University family for establishment the department of chemistry

^a *Department of Chemistry, Ahar Branch, Islamic Azad University, Ahar, Iran*

^b *Department of Chemistry, Faculty of Science, Soran University, PO Box 624, Soran, Kurdistan Regional Government, Iraq*

Abstract

α -Aminophosphonates are synthesized efficiently by one-pot reaction of aldehydes or ketones, amines, trialkyl phosphites in the presence of Natrolite zeolite as a natural catalyst under solvent-free conditions. Furthermore, the catalyst can be reused for several times without any significant loss of catalytic activity.

KEYWORDS

α -Aminophosphonates; Trialkyl phosphite; Solvent-free; Natrolite zeolite

1. Introduction

The synthesis of α -aminophosphonates which are considered as analogues of amino acids has been a focus of considerable attention in synthetic organic chemistry as well as in medicinal chemistry (Allen et al., 1989; Giannousis, Bartlett, 1987; Bartlett and Kezer, 1984). The addition of phosphorous nucleophiles to imines is a general reported synthetic method for the preparation of α -aminophosphonates. This reaction is usually catalyzed by Lewis acids such as SnCl_2 , SnCl_4 , ZnCl_2 and MgBr_2 . However, these reactions cannot proceed in one-pot from a carbonyl compound, an amine and a phosphite. Generation of water during the course of the reaction can decompose or deactivate these Lewis acids (Laschat and Kunz, 1992; Genet et al., 1992). This

*Correspondence author. Tel.: +964 6635066660; fax: +964 7703643421.
E-mail address: smohammad.sajadi@gmail.com, mohammad.s@soranu.com
(S. Mohammad Sajadi)

drawback has been overcome by some recent methods using lanthanide triflates/magnesium sulfate (Qian and Huang, 1998), InCl_3 (Ranu et al., 1999), $\text{TaCl}_5\text{-SiO}_2$ (Chandrasekhar et al., 2001), ZrCl_4 (Yadav et al., 2001), $\text{Sc}(\text{DS})_3$ (Manabe and Kobayashi, 2000), $\text{H}_3\text{PW}_{12}\text{O}_{40}$ (Heydari et al., 2007) $\text{BiNO}_3\cdot 5\text{H}_2\text{O}$ (Bhattacharya and Kaur, 2007), $\text{Mg}(\text{ClO}_4)_2$ (Bhagat and Chakraborti, 2007) and α -cyclodextrine (Kaboudin and Sorbiun, 2007). However, these methods involve either long reaction times, low yields of the products, required stoichiometric amount of reagents, use of solvent, use of additives or expensive catalysts. Thus, the development of a new procedure for the synthesis of α -aminophosphonates would be highly desirable.

In recent years there has been a tremendous upsurge of interest in various chemical transformations performed under heterogeneous, homogeneous catalysis and solvent-free conditions (Kamali, T.A. et al., 2009; Modarresi-Alam et al., 2009; Nasrollahzadeh et al., 2009; Nasrollahzadeh et al., 2010; Habibi et al., 2010; Habibi et al., 2011; Habibi et al., 2012; Mohammadi et al., 2010). Moreover, using inexpensive and non corrosive heterogeneous catalysts, chemical transformations occur with better efficiency, higher purity of the products, and easier workup, with evident economic and ecological advantages especially for industrial processes. Zeolites are crystalline hydrated aluminosilicates of the alkaline earths. The application of inorganic solid acids, especially zeolites, as effective heterogeneous catalysts for organic synthesis has received considerable attention in the recent decades due to their unique physical and chemical properties such as shape, selectivity, acidic and basic nature and their thermal stability (Hoelderich and Haft, 1991). Natrolite, $\text{Na}_2[\text{Al}_2\text{Si}_3\text{O}_{10}]\cdot 2\text{H}_2\text{O}$, is one of the fibrous zeolites with the framework constructed from the chains of corner-sharing Al and Si oxygen tetrahedral (Line and Kearley, 1998).

Recently, Nasrollahzadeh and co-workers reported the synthesis of tetrazoles using natural Natrolite zeolite as a heterogeneous catalyst (Nasrollahzadeh et al., 2009; Habibi et al., 2011).

Recently, we have described a sufficiently simple and convenient synthesis of formamides from the corresponding amines using HEU zeolite under solvent-free conditions (Mohammadi-Aghdam et al., 2012)

We herein report an efficient procedure for the synthesis of α -aminophosphonates under solvent-free conditions using Natrolite zeolite as a reusable and natural catalyst (Scheme 1). The results of the present work show the desired product in excellent yield.

Scheme 1

2. Experimental

All reagents were purchased from Merck and Aldrich and used without further purification. Products were characterized by spectroscopy data (IR, ^1H NMR and ^{13}C NMR spectra) and melting point. The NMR spectra were recorded in CDCl_3 . ^1H NMR spectra were recorded on a Bruker Avance DRX 500 MHz instrument. The chemical shifts (δ) are reported in ppm relative to the TMS as internal standard. J values are given in Hz. ^{13}C NMR spectra were recorded at 125 Hz. IR (KBr) spectra were recorded on a Shimadzu 470 spectrophotometer, respectively. Melting points were taken in open capillary tubes with a BUCHI 510 melting point apparatus and were uncorrected. TLC was performed on silica gel polygram SIL G/UV 254 plates. Natural Iranian natrolite zeolite from the Hormak area (Zahedan city, Sistan & Baluchestan province, Iran) was used in this work (Nasrollahzadeh et al., 2009).

2.1. Preparation of α -aminophosphonate

The required carbonyl compound (1 mmol), an amine (1 mmol) and diethyl phosphite (1 mmol) were added to Natrolite zeolite (0.05 g) and the mixture was heated in an oil bath at 65°C . The progress of the reaction was monitored by TLC (eluent: EtOAc/nhexane, 20:80). After the reaction was complete, EtOAc (2×20 mL) was added to the reaction mixture and the catalyst was separated by filtration. The organic solvent was removed under reduced pressure. After purification by chromatography on silica gel (ethyl acetate/n-hexane 20:80) the α -aminophosphonate were obtained. All the products are known compounds and the spectral data and melting points were identical to those reported in the literature (Heydari et al., 2007; Bhagat and Chakraborti, 2007; Hosseini-Sarvari, 2008; Heydari et al., 1998; Tajbakhsh et al., 2008).

2.1.1. Dimethyl(phenyl)-*N*-(phenyl)aminomethylphosphonate (Table 2, Entry 2)

^1H NMR (^1H (500 MHz, CDCl_3): 3.50 (d, 3H, $J = 10.5$ Hz), 3.80 (d, 3H, $J = 10.5$ Hz), 4.81 (1H, d, $J = 24$ Hz), 4.84 (s, 1H, br), 6.65 (d, 2H, $J = 8.0$ Hz), 6.75 (t, 1H, $J = 7.2$ Hz), 7.10 (t, 2H, $J = 7.6$ Hz), 7.30 (t, 1H, $J = 7.5$ Hz), 7.40 (t, 2H, $J = 7.4$ Hz), 7.51 (d, 2H, $J = 7.4$ Hz); ^{13}C NMR (125 MHz, $\text{DMSO}-d_6$): 54.2 (d, OCH_3 , $^2J_{\text{P}6\text{C}} = 7.0$ Hz), 54.2 (OCH_3 , $^2J_{\text{P}6\text{C}} = 6.8$ Hz), 56.2 (d,

CH, $^1J_{\text{P6C}} = 150$ Hz), 114.2 (CH), 119.0 (CH), 128.3 (d, CH, $^3J_{\text{P6C}} = 5.8$ Hz), 128.4 (d, CH, $^3J_{\text{P6C}} = 3.1$ Hz), 129.2 (CH), 131.2 (CH), 136.1 (C), 146.6 (d, C, $^2J_{\text{P6C}} = 14.5$ Hz).

3. Results and Discussion

Initially to optimize the reaction conditions, we tested the reaction of aniline and 4-methylbenzaldehyde as a simple model substrate in different solvents and also solvent-free conditions in the presence of Natrolite zeolite as a reusable and natural catalyst. As shown in Table 1, the yields of the reaction under solvent-free conditions are higher and the reaction time is shorter. Therefore, we employed the solvent-free conditions for the synthesis of α -aminophosphonates. The optimum amount of Natrolite zeolite was found to be 0.05 g in the presence of 4-methylbenzaldehyde (1 mmol), aniline (1 mmol) and triethyl phosphite (1 mmol).

Table 1

In order to examine the scope of this process, reactions of several aldehydes, amines (primary and secondary), and trimethyl or triethyl phosphate were examined in the presence of 0.05g Natrolite zeolite under solvent-free conditions. Benzaldehyde and electron-deficient aromatic aldehydes reacted with aromatic and aliphatic amines to give the corresponding α -aminophosphonates in high yields. The present method does not require any additives or promoters, and the results are shown in Table 2. It is important to note that when benzaldehyde, aniline and trimethyl phosphate were reacted in the absence of the Natrolite zeolite, the reaction did not proceed. In addition to aldehydes, some ketones were also screened to carry out the three-component couplings by Natrolite zeolite and solvent-free conditions.

Table 2

After the removal of the solvent and purification, the products were characterized by IR, ^1H NMR, ^{13}C NMR and melting points.

In a typical experiment, after completion of the reaction, Natrolite zeolite was isolated by simple filtration, washed with water (10 mL) and ethanol (5 mL) three times, dried and

successively used several times without any significant loss of activity. In fact, the reaction benzaldehyde (Table 2, entry 1) with aniline and triethyl phosphate has been repeated five times using the same catalyst with respectably high yields: 89-93%. The XRD patterns before and after the reaction revealed that the zeolite retained its crystallinity throughout.

4. Conclusion

In conclusion, we have developed a novel and highly efficient method for the synthesis of α -aminophosphonates by treatment of aldehydes or ketones with amines and trialkyl phosphite in the presence of Natrolite zeolite as an effective catalyst. The significant advantages of this methodology are high yields, short reaction times and a simple work-up procedure. Natrolite zeolite as a catalyst is important from an environmental point of view and from the view point of economic considerations, because it produces little waste. It also has excellent activity on an industrial scale and in most cases can be recovered from reaction mixtures and reused.

References

- Allen, M., Fuhrer, C.W., Tuck, B., Wade, R., Wood, J. M., 1989. *J. Med. Chem.* 32, 1652.
- Giannousis, P.P. P., Bartlett, A., 1987. *J. Med. Chem.* 30, 1603.
- Bartlett, P.A., Kezer, W.B., 1984. *J. Am. Chem. Soc.* 106, 4282.
- Laschat, S., Kunz, H., 1992. *Synthesis* 90.
- Genet, J.P., Yziel, J., Port, M., Touzin, A.M., Roland, S., Thorimbert, S., Tanier, S., 1992. *Tetrahedron Lett.* 33, 77.
- Qian, C., Huang, T., 1998. *J. Org. Chem.* 63, 4125.
- Ranu, B.C., Hajra, A., Jana, U., 1999. *Org. Lett.* 1, 1141.
- Chandrasekhar, S., Prakash, S.J., Jagadeshwar, V., Narsihmulu, Ch., 2001. *Tetrahedron Lett.* 42, 5561.
- Yadav, J.S., Reddy, B.V.S., Sarita Raj, K., Bhaskar Reddy, K., Prasad, A. R., 2001. *Synthesis* 2260.
- Manabe, K., Kobayashi, S., 2000. *Chem. Commun.* 669.
- Heydari, A., Hamadi, H., Pourayoubi, M., 2007. *Catal. Commun.* 8, 1224.
- Bhattacharya, A.K., Kaur, T., 2007. *Synlett* 5, 745.
- Bhagat, S., Chakraborti, A.K., 2007. *J. Org. Chem.* 72, 1263.

Kaboudin, B., Sorbiun, M. 2007. *Tetrahedron Lett.* 48, 9015.

Kamali, T.A., Bakherad, M., Nasrollahzadeh, M., Farhangi, S., Habibi, D. 2009. *Tetrahedron Lett.* 50, 5459.

Modarresi-Alam, A.R., Nasrollahzadeh, M., 2009. *Turk. J. Chem.* 33, 267.

Nasrollahzadeh, M., Bayat, Y., Habibi, D., Moshaei, S., 2009. *Tetrahedron Lett.* 50, 4435.

Kamali, T.A., Habibi, D., Nasrollahzadeh, M., 2009. *Synlett* 2601.

Habibi, D., Nasrollahzadeh, M., Faraji, A.R., Bayat, Y., 2010. *Tetrahedron* 66, 3866.

Habibi, D., Nasrollahzadeh, M., 2010. *Synth. Commun.* 40, 3159.

Habibi, D., Nasrollahzadeh, M., 2011. *Synth. Commun.* 41, 2135.

Habibi, D., Nasrollahzadeh, M., 2012. *Monatsh fur Chem.* 143, 925.

Habibi, D., Nasrollahzadeh, M., 2012. *Synth. Commun.* 42, 2023.

Mohammadi, B., Hosseini Jamkarani, S.M., Kamali, T.A., Nasrollahzadeh, M., Mohajeri, A., 2010. *Turk. J. Chem.* 34, 613.

Hoelderich, W.F., Haft, B. A., 1991. *Structure-activity and selectivity relationships in heterogeneous catalysis*, Elsevier Publishers: Amsterdam.

Line, C.M.B., Kearley, G.J., 1998. *Chem. Phys.* 234, 207.

Nasrollahzadeh, M., Habibi, D., Shahkarami, Z., Bayat, Y., 2009. *Tetrahedron* 65, 10715.

Habibi, D., Nasrollahzadeh, M., Kamali, T.A., 2011. *Green Chem.* 13, 3499.

Bahari, S., Mohammadi-Aghdam, B., Sajadi, S. M., Zeidali, F., 2012. *Bull. Korean Chem. Soc.* 33, 2251.

Hosseini-Sarvari, M., 2008. *Tetrahedron*, 64, 5459.

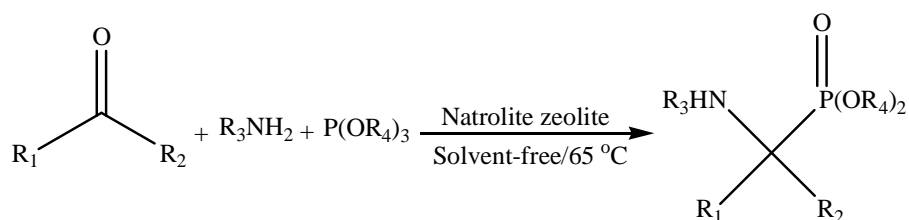
Heydari, A., Karimian, A., Ipaktschi, J., 1998. *Tetrahedron Lett.* 39, 6729.

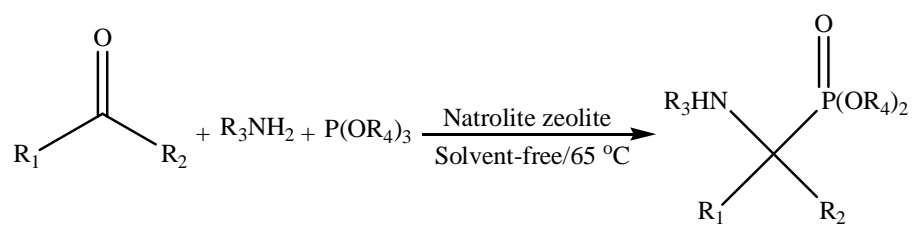
Tajbakhsh, M., Heydari, A., Alinezhad, H., Ghanei, M., Khaksar S., 2008. *Synthesis* 352.

Graphical Abstract

Natrolite zeolite: A natural and reusable catalyst for one-pot synthesis of α -aminophosphonates under solvent-free conditions

Siavash Bahari and S. Mohammad Sajadi*



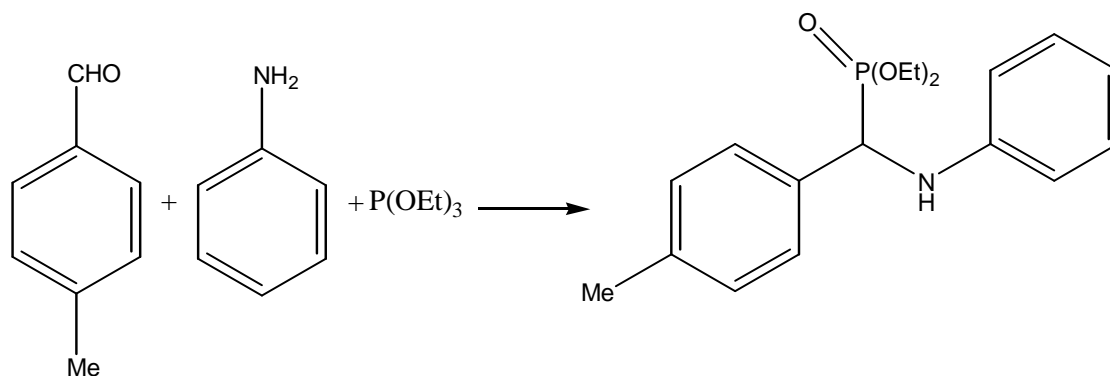


Scheme 1

Table captions

Table 1 Optimization of the synthesis of α -aminophosphonates^a

Table 2 Synthesis of α -aminophosphonates from aldehydes or ketones mediated by Natrolite zeolite under solvent-free conditions

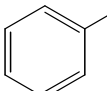
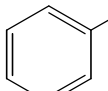
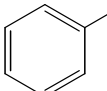
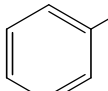
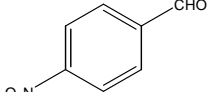
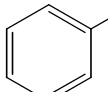
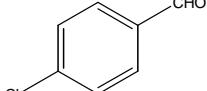
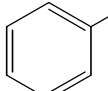
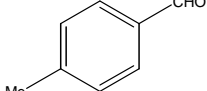
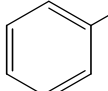
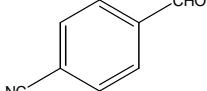
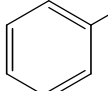
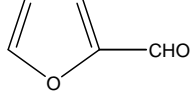
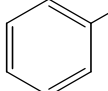
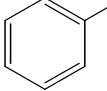
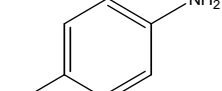
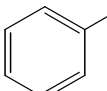
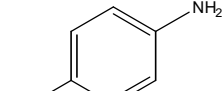
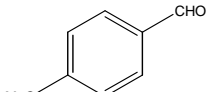
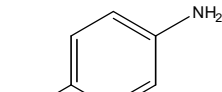
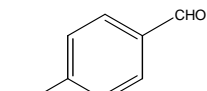
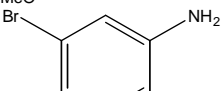
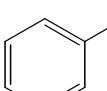
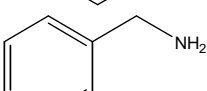
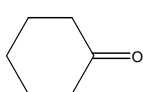
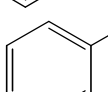
Table 1 Optimization of the synthesis of α -aminophosphonates^a

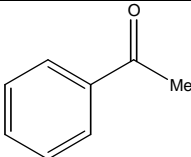
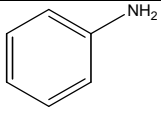
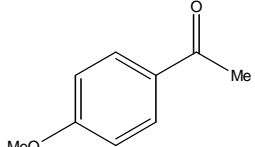
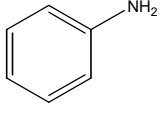
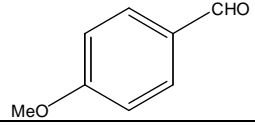
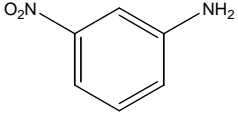
Entry	Catalyst	Solvent	Time	Yield ^b (%)
1	Nano ZnO (20 mol%)	Solvent-free/100 °C	20 h	53
2	MgO (20 mol%)	Solvent-free/100 °C	30 h	0
3	KAl(SO ₄) ₂ ·12H ₂ O (20 mol%)	THF/rt	20 h	37
4	KAl(SO ₄) ₂ ·12H ₂ O (20 mol%)	PhMe/rt	20 h	40
5	Natrolite zeolite (0.05 g)	EtOH/65 °C	40 h	0
6	Natrolite zeolite (0.05 g)	THF/65 °C	40 h	0
7	Natrolite zeolite (0.05 g)	Solvent-free/rt	8 h	72
8	Natrolite zeolite (0.05 g)	Solvent-free/100 °C	4 h	89

^aReaction conditions: 4-methylbenzaldehyde (1 mmol), aniline (1 mmol), triethyl phosphite (1 mmol) and Natrolite zeolite (0.05 g) at 65 °C.

^bIsolated yield.

Table 2 Synthesis of α -aminophosphonates from aldehydes or ketones mediated by Natrolite zeolite under solvent-free conditions

Entry	Carbonyl compounds	Amine	P-Nucleophile	Time (h)	Yield ^a %
1			P(OEt) ₃	4	93
2			P(OMe) ₃	4	92
3			P(OEt) ₃	13	93
4			P(OEt) ₃	3	89
5			P(OEt) ₃	4.5	91
6			P(OEt) ₃	3	91
7			P(OEt) ₃	3	90
8			P(OEt) ₃	3	90
9			P(OEt) ₃	3	91
10			P(OEt) ₃	3	89
11			P(OEt) ₃	3	91
12			P(OEt) ₃	5	92
13			P(OEt) ₃	4	Trace

14			P(OEt) ₃	5	84
15			P(OEt) ₃	6	82
16			P(OEt) ₃	5	85

^a Yield refer to the pure isolated products.