

RAPID AND FACILE SYNTHESIS OF ACYL AZIDES FROM ACYL HALIDES USING A POLYMER-SUPPORTED AZIDE ION UNDER HETEROGENEOUS CONDITIONS

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Abstract In this article a rapid and facile method for synthesis of acyl azide is described. The cross-linked poly(*N*-methyl-4-vinylpyridinium) azide ion, [P₄-VP]N₃ is prepared and used as an efficient polymeric reagent for synthesis of acyl azides from acyl halides at room temperature under heterogeneous conditions. Various benzoyl halides, with electron-withdrawing groups as well as electron-donating groups, were transformed into the corresponding benzoyl azides in high to excellent yields in short reaction times. The acyl azide products were characterized by FT-IR, and some of them were also characterized by ¹H- and/or ¹³C-NMR spectroscopy, and physical properties were compared to literature values of known compounds. The spent polymeric reagents can be regenerated and reused for several times without losing their activity. Relative to the reported methods, the present method has the advantages of operational simplicity, mild reaction conditions, fast reaction rates, simple reaction work-up and lower hazardous and potentially explosive nature. Also the present method is the first procedure for the synthesis of acyl azides from acyl halides by using a polymer-supported azide ion under heterogeneous conditions.

Keywords: Acyl azide; Acyl halide; Polymeric reagent; Heterogeneous condition.

INTRODUCTION

Like hydrogen azide most other azides are explosive substances that decompose with the evolution of nitrogen through the slightest input of external energy, for example pressure, impact, or heat.

Organic azides are valuable intermediates in organic synthesis^[1–5]. They are used in cycloadditions, the synthesis of anilines and *N*-alkyl-substituted anilines^[6], as well as precursors for nitrenes.

Acyl azides are widely utilized in industry and act as a chemical feed-stock for a range of useful materials in organic chemistry^[1, 5, 7], and especially pharmaceuticals^[8], dyes^[9] and agrochemicals^[10]. They are useful for the preparation of amides and heterocyclic compounds, and also undergo facile thermal rearrangement to isocyanates. Isocyanates are also prepared^[7] in a one-pot procedure by treating the acid chloride with ammonium or metal azide without isolating the intermediate acyl azide.

Acyl azides are usually prepared from acid derivatives such as acid halides and acyl hydrazides^[1, 11], or mixed anhydrides^[12–15]. Also, several methods are available to accomplish this transformation; the majority involves the conversion of carboxylic acids to acid chlorides or anhydrides^[16–20], which are then reacted with azide reagents. There are a few reports on the direct conversion of carboxylic acids to acyl azides by using acid activators such as SOCl₂-DMF^[21], ethyl chloroformate^[22], diphenylphosphonyl azide (DPPA)^[23], *N*-chlorosuccinimide/PPh₃^[24], triphosgene^[25] and cyanuric chloride^[26].

Attempts have also been made to prepare acyl azides directly from aldehydes by using special type of

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Received August 10, 2012; Revised September 18, 2012; Accepted September 24, 2012

doi: 10.1007/s10118-013-1290-z

reagents such as chromic anhydride-trimethylsilyl azide^[27], triazidochlorosilane-manganese dioxides^[28], Dess-Martin periodinane (DMP)^[29], *tert*-butyl hypochlorite^[30] and iodine azide^[31].

However, these methods suffer from their hazardous and potentially explosive nature, which inhibits their widespread use. In this context, notwithstanding the availability of many preparative methods, the restrictions that accompany some of them make new, mild, and selective procedures highly desirable.

Recently, the chemistry of functional polymers has received great attention and became a practical method for the efficient preparation of novel chemical libraries^[32–34]. These polymeric reagents are generally used in single-step reactions; their main advantage over non polymeric reagent is their insolubility in the reaction medium and consequently their easier work-up by a simple filtration. The reactions often can be driven to completion using excess amounts of reagents without the fear of separation of the excess of reagents from the products. The spent polymeric reagents usually can be removed quantitatively and regenerated. In addition, anions bound to the macroporous resin have the advantage that often react successfully in nonpolar solvents. These reagents usually can be prepared from commercial anion exchange resins or polymers such as cross-linked poly(4-vinylpyridine) as support.

Although polymer-supported reagents especially anion exchange resins have been widely applied in organic synthesis^[32–38], but, there are a few reports in organic transformations based on polymeric azide reagents. Taylor *et al.* reported the synthesis of polymer-supported phosphorylazide and used it for conversion of carboxylic acids to ureas or urethane in the presence of amines or alcohols respectively^[39]. Bols *et al.* reported polystyrene supported diazidoiodate and used it for conversion of aldehydes to carbamoyl azides and benzyl ethers to azidobenzyl ethers^[40]. However, there is no report in the literature on synthesis of acyl azides based on polymeric reagents. In continuing of our studies in organic transformations by using cross-linked poly(4-vinylpyridine) supported azide ion^[35–38], acyl azides are chosen as the target compounds in this work. Herein we wish to report an improved, rapid and facile synthesis of acyl azides from acyl halides by using a polymer supported azide ion under mild, nonaqueous and heterogeneous conditions. Although a key feature of the present paper is its clean work-up with easy removal of acyl azide products due to the heterogeneous nature of the reaction, all due precaution should be taken.

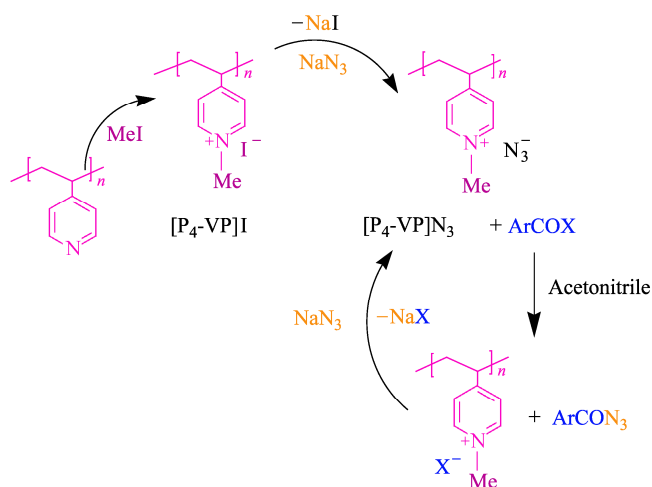
EXPERIMENTAL

Materials

Chemicals were either prepared in our laboratory or were purchased from Fluka (Buchs, Switzerland), Aldrich (Milwaukee, WI) and Merck (Germany) chemical companies. Poly(4-vinylpyridine) cross-linked with 2% divinyl benzene (DVB), [P4-VP] 2% DVB, was purchased from Fluka (Buchs, Switzerland). Conversion of [P4-VP] 2% DVB to cross-linked poly(*N*-methyl-4-vinylpyridinium) iodide, [P₄-VP]I, and cross-linked poly(*N*-methyl-4-vinylpyridinium) azide, [P₄-VP]N₃, were taken according to the reported procedure (Scheme 1)^[35]. Progress of the reaction was followed by thin layer chromatography (TLC) using silica gel Poly Gram SIL G/UV 254 plates. All products were characterized by comparison of their melting point, FT-IR, ¹H-NMR and ¹³C-NMR spectral data with those of known samples, and all yields refer to the isolated pure products. Melting points were determined with a Buchi melting point B-540 B.V. CHI apparatus. FT-IR spectra were obtained by using a Bruker, Equinox (model 55) and NMR spectra were recorded on a Bruker AC 400, Avance DPX spectrophotometer at 400 MHz for ¹H- and at 100 MHz for ¹³C-NMR in CDCl₃ solutions.

Preparation of [P₄-VP]N₃

Cross-linked poly(*N*-methyl-4-vinylpyridinium) azide, [P₄-VP]N₃, was synthesized and its capacity was determined according to our reported procedure (Scheme 1)^[35]. The obtained capacity of the polymer was 3.4 mmol of azide ion per gram of polymer.



Scheme 1 Preparation of the polymeric reagent, reaction pathway and regeneration of the polymeric reagent

General Procedure for Conversion of Acyl Halides to the Corresponding Acyl Azides by Using $[P_4VP]N_3$

To a mixture of acyl halide (1 mmol) and acetonitrile (5 mL) in a round-bottomed flask (50 mL), 0.73 g of cross-linked poly(*N*-methyl-4-vinylpyridinium) azide ion (2.5 mmol of azide ion) was added, and the mixture was slowly stirred on a magnetic stirrer at room temperature for an appropriate time, as indicated in Table 2 (shown later, 10–70 min). Reaction was monitored by TLC [eluent: *n*-hexane-ethyl acetate (90/10)]. After completion of the reaction, the suspension was filtered and washed with acetonitrile (2×5 mL). The solvent was evaporated and the pure acyl azide compounds were obtained in high to excellent yields (75%–95%) (Table 2), except 2-substitutedbenzoyl chlorides that the conversions were not completed and the yield of the corresponding 2-substitutedbenzoyl azides was low (Table 2, Entries 8 and 15). If further purification was needed, flash chromatography on silica gel [eluent: *n*-hexane-ethyl acetate (90/10)] was used and highly pure products were obtained.

Preparation of *p*-Nitrobenzoyl Azide (Table 2, Entry 2) Using $[P_4VP]N_3$; a Typical Procedure

To a mixture of *p*-nitrobenzoyl chloride (175 mg, 1 mmol) and acetonitrile (5 mL) in a round-bottomed flask (50 mL), 0.73 g (2.5 mmol) of cross-linked poly(4-vinylpyridine) supported azide ion was added, and the mixture was slowly stirred on a magnetic stirrer at room temperature for 10 minutes. The suspension was filtered and washed with ethanol (2×5 mL). The solvent was evaporated and the pure *p*-nitrobenzoyl azide was obtained in 95% yield (172 mg). Mp. = 71 °C; FT-IR (neat) $\nu_{\max}$ (cm⁻¹) = 3112 (C–H, aromatic), 2185 and 2140 (–N=N=N, asym) 1691 (C=O), 1603 (C=C), 1534 and 1350 (NO₂) 1226 (–N=N=N, sym), 1178 and 1108 (C–N), 990, 874, 844, 706; ¹H-NMR (400 MHz, CDCl₃, δ): 8.26 (2H, d, *J* = 7.01 Hz), 8.39 (2H, d, *J* = 6.98 Hz); ¹³C-NMR (100 MHz, CDCl₃, δ): 124.29, 29.5 and 205.65 (solvent), 130.69, 136.14, and 151.7 (Ar), 171.19 (C=O).

Regeneration of $[P_4VP]N_3$

The cream-colored spent polymeric reagent (1.00 g) was added to a mixture of sodium azide (0.65 g) in distilled water (20 mL), and the mixture was slowly stirred at room temperature for 24 h. The reaction mixture was filtered and washed with distilled water (3×8 mL) and with diethyl ether (10 mL). The polymer was dried under vacuum at 40 °C, over P₂O₅, overnight and 1.20 g $[P_4VP]N_3$ was obtained.

The capacity of the regenerated polymer was determined and it was found to have the same capacity as the original form (3.4 mmol of azide ion per gram of polymer). The regenerated polymer was reused several cycles, without losing its activity (Table 2, entries 3–6).

RESULTS AND DISCUSSION

In this paper we reported the first procedure for rapid and facile azidation of acyl halides by using the cross-linked poly(*N*-methyl-4-vinylpyridinium) azide ion, [P₄-VP]N₃. This polymeric reagent was prepared as described in our previously reported method^[35].

The reaction is believed to follow the typical pathway as shown in Scheme 1. The spent polymeric reagent was easily regenerated by treatment with an aqueous solution of sodium azide (Scheme 1).

In order to increase the yield of the acyl azide products, optimization of the reaction conditions was accomplished. Experiments were carried out as shown in Table 1. The best result was obtained when the molar ratio of [P₄-VP]N₃/acyl azide was 2.5/1 in acetonitrile as solvent (Table 1, Entry 2). These conditions were used for subsequent reactions. In *n*-hexane, the reaction was slow and gave only a 59% isolated yield of acyl azide after 60 min (Table 1, Entry 8). Solvents such as dichloromethane, acetone and chloroform afforded high yields.

Table 1. Optimization of the reaction conditions for the conversion of *p*-nitrobenzoyl chloride (1 mmol) to the corresponding benzoyl azide using [P₄-VP]N₃ in different solvents at room temperature

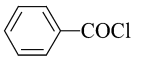
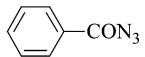
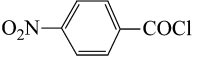
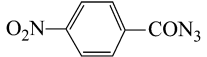
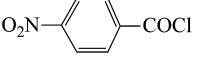
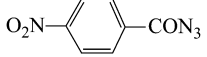
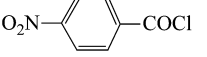
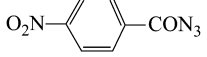
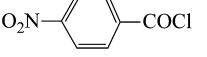
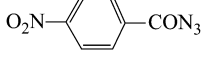
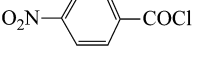
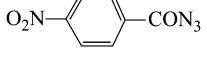
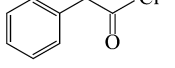
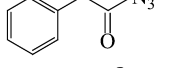
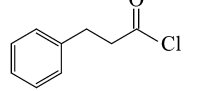
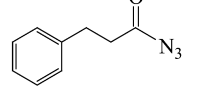
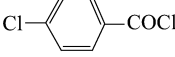
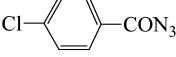
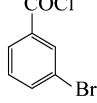
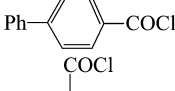
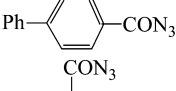
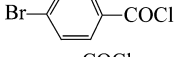
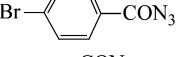
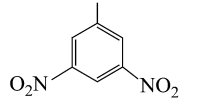
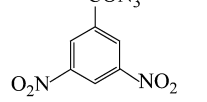
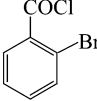
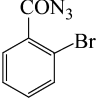
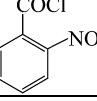
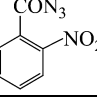
Entry	Solvent	Reaction time (min)	[P ₄ -VP]N ₃ (mmol of azide ion)	Isolated yield (%)
1	Acetonitrile	10	3	95
2	Acetonitrile	10	2.5	95
3	Acetonitrile	100	2	80
4	Acetonitrile	100	1.5	71
5	Acetonitrile	100	1	42
6	Acetone	100	2.5	87
7	CH ₂ Cl ₂	100	2.5	91
8	<i>n</i> -Hexane	100	2.5	59
9	CHCl ₃	100	2.5	88
10	C ₆ H ₅ CH ₃	100	2.5	72

We next examined the scope and generality of the method. Various acyl halides were studied, and the results are summarized in Table 2. As can be seen in Table 2, a wide variety of benzoyl halides, with electron-withdrawing groups as well as electron-donating groups, were transformed into the corresponding acyl azides with high to excellent yields in very short reaction times (10–70 min). As Table 2 reveals, the steric effect was observed and when 2-substituted benzoyl chloride was subjected to this approach the conversions were not completed. (Table 2, Entries 15 and 16). For example when 2-bromobenzoyl chloride was subjected to this approach after 70 min, only 11% 2-bromobenzoyl azide product was obtained and 89% of the substrate was remained intact.

We have also successfully applied this new method on rather large scale. For example, up to 15 mmol of *p*-nitrobenzoyl chloride (Table 2, Entry 2) could be converted into the corresponding acyl azide without any loss of efficiency.

The acyl azide products were characterized by FT-IR, ¹H- and ¹³C-NMR spectroscopy, and their physical properties were compared with those of the known samples. In this respect, the appearance of two strong bands in the region 2130–2230 cm^{−1} for asymmetric stretching vibration of −N=N=N groups, a strong band at 1680–1690 (C=O) and a weak band at 1225–1255 cm^{−1} for symmetric stretching vibration of −N=N=N groups indicate the formation of the corresponding acyl azides. The surprising feature of the data is that the asymmetric −N=N=N stretching absorption, which always is observed as a strong single bond^[35, 41], now appears as a doublet. When, at first this was observed for benzoyl azide (Table 2, entry 1), it was thought that the product has decomposed in the period between the preparation and recording the spectrum. So, the spectrum of a freshly prepared specimen of benzoyl azide was taken and the same results were observed. These results are in agreement with very recently reported investigations on infrared spectra of acid azides by Lieber and Oftedahl^[42]. The FT-IR, ¹H- and ¹³C-NMR spectral data of some selected acyl azide products are given in Table 3.

Table 2. Conversion of acyl halides to the corresponding acyl azides using [P₄-VP]N₃ in acetonitrile at room temperature

Entry	Substrate	Product ^a	Time (min)	Yield ^b (%)
1			25	85
2			10	95
3 ^c			10	95
4 ^c			10	95
5 ^c			15	94
6 ^c			18	94
7			50	80
8			50	77 ^d
9			30	90
10			35	75
11			50	89
12			15	76
13			35	95
14			25	92
15			70	11
16			60	30

^a Products were characterized by comparison of their IR and NMR spectra and physical data with those of known samples; ^b Isolated yields; ^c The entries 3–6 refer to the use of [P₄-VP]N₃ that is recycled first, second, third and fourth times, respectively, under identical conditions; ^d The 3-phenylpropionyl azide decompose upon standing in air at room temperature so, the spectrum of a freshly prepared sample of the corresponding acyl azide was taken.

Table 3. Characteristic spectral data of some acyl azide products

Entry	Product	$\nu_{\max}$ (cm ⁻¹)	¹ H-NMR, δ	¹³ C-NMR, δ
1		3104, 2229, 2153, 1686, 1628, 1536, 1459, 1345, 1255, 1164, 1079, 1055, 922, 743, 729	8.97 (2 H, s), 9.08 (1 H, s)	—
2		3090, 2135, 1679, 1601, 1485, 1451, 1405, 1248, 1180, 1024, 985, 853, 781, 738, 691	7.45 (1 H, t), 7.53 (2 H, d), 7.45 (2 H, d), 7.84 (2 H, d), 8.10 (2 H, d)	127.57, 127.66, 128.94, 129.47, 129.86, 130.24, 139.73, 147.25, 172.10
3		3090, 2171, 2131, 1676, 1580, 1479, 1398, 1370, 1284, 1234, 1179, 1166, 1107, 1070, 1014, 989, 840, 718, 675	7.76 (2 H, d), 7.93 (2 H, d)	129.48, 130.23, 131.30, 132.58, 171.73
4		3050, 2172, 2137, 1684, 1568, 1421, 1358, 1265, 1228, 1184, 996, 895, 723, 689	7.52, (1 H, t), 7.87 (1 H, d), 7.88 (1 H, d), 7.98 (1 H, d), 8.09	122.70, 128.39, 131.32, 132.10, 133.13, 137.59, 171.19
5		3096, 2176, 2133, 1677, 1567, 1408, 1232, 1167, 1088, 991, 891, 747, 678	7.73 (2 H, d, $J = 5.36$), 7.90 (2 H, d, $J = 5.38$)	129.51, 130.18, 131.29, 132.56, 171.70
6		3093, 2199, 2153, 1685, 1615, 1526, 1475, 1346, 1322, 1288, 1250, 1180, 1088, 1014, 919, 906, 852, 813, 735, 704, 653	7.90 (1 H, t), 8.41 (1 H, d), 8.56 (1 H, d), 8.73 (1 H, t)	123.98, 128.98, 131.10, 132.65, 135.18, 170.90
7		3112, 2186, 2140, 1691, 1604, 1534, 1350, 1320, 1227, 1179, 1109, 990, 874, 844, 706	8.26 (2 H, d, $J = 7.01$), 8.39 (2 H, d, $J = 6.98$)	124.29, 130.69, 136.14, 151.70, 171.19

In Table 4 the reaction times and isolated yields of some obtained products by the present method are compared with those obtained by the reported classical methods^[25, 26, 29, 30, 43]. As Table 4 reveals, in this method, the reaction time is always shorter than that in the previously reported methods. This can probably be attributed to the local concentration of azide ion species inside the pores.

Table 4. Comparison of the reaction times and isolated yields of some obtained products from the present method with those from the reported classical method^[25, 26, 29, 30, 43]

Entry	Product	Reaction time	Isolated yield (%)	Mp. (°C)	Ref.
1		10 h	85	—	43 ^a
2		24 h	81	Oil	25 ^b
3		3 h	86	Oil	26 ^c
4		15 h	89	25–27	29 ^d
5		24 h	84	25–27	30 ^e
6		25 min	85	Oil	Table 2, Entry 1
7		10 h	71	—	43
8		24 h	55	68–69	25
9		3 h	84	71	26
10		3 h	85	64–66	29
11		24 h	83	65–67	30

Table 4. Continued

Entry	Product	Reaction time	Isolated yield (%)	Mp. (°C)	Ref.
12		10 min	95	71	Table 2, Entry 2
13		24 h	50	100–102	25
14		3 h	71	69	26
15		10 h	66	–	43
16		25 min	92	71	Table 2, Entry 14
17		24 h	85	86–88	25
18		3 h	95	Oil	29
19		10 h	83	–	43
20		3 h	80	Oil	26
21		24 h	80	Oil	30
22		50 min	80	Oil	Table 2, Entry 7
23		3 h	93	38	26
24		10 h	94	–	43
25		24 h	80	43–44	30
26		30 min	90	39–41	Table 2, Entry 7
27		24 h	79	Oil	30
28		50 min	77	Oil	Table 2, Entry 7

^a In Ref. [43] acyl azides were prepared from carboxylic acids and NaN_3 in the presence of boronic acid, in acetonitrile at room temperature for 10 h; ^b In Ref. [25] acyl azides were prepared from carboxylic acids and NaN_3 in the presence of triphosgene in acetone at 0 °C for 24 h; ^c In Ref. [26] acyl azides were prepared from carboxylic acids and NaN_3 in the presence of cyanuric chloride in CH_2Cl_2 at 0–50 °C for 3 h; ^d In Ref. [29] acyl azides were prepared from aldehydes and NaN_3 in the presence of Dess-Martin periodinane in CH_2Cl_2 at 0 °C for 1–4.5 h.; ^e In Ref. [30] acyl azides were prepared from aldehydes and NaN_3 in the presence of *tert*-butyl hypochlorite in CCl_4 at room temperature for 24 h.

In summary, in this article we have developed a general method for direct conversion of acyl halides to corresponding acyl azides using cross-linked poly(*N*-methyl-4-vinylpyridinium) azide ion as a useful and efficient polymeric reagent. The method is simple and occurs under mild and heterogeneous conditions. With this reagent the work-up of the reaction mixture is easy, reaction takes place at room temperature and the reaction time is shorter than that by using previously reported methods. The polymeric reagent was recovered quantitatively by filtration and it was regenerated and reused for several cycles. Further application of this reagent in organic transformation is currently being investigated in our laboratory. In addition, there is current research and general interest in heterogeneous systems because of the importance of such systems in industry and in developing technologies^[44].

CONCLUSIONS

We have developed an efficient, rapid and experimentally simple method for conversion of acyl halides to corresponding acyl azides. The present method has the advantages of operational simplicity, mild reaction conditions, ready availability, fast reaction rates and simple reaction work-up.

REFERENCES

- 1 Patai, S., "The chemistry of the azido group", Interscience, New York, 1971, p. 397
- 2 Patai, S. and Baciocchi, E., "The chemistry of halides, pseudo-halides and azides", Supplement D, Wiley, Chichester, UK, 1983, p. 321
- 3 Patai, S., "Chemistry of halides, pseudo-halides and azides, Part 1", Wiley, Chichester, 1995, p. 1003
- 4 Scriven, E.F.V., "Monograph: azides and nitrenes-reactivity and utility", Academic Press, New York, 1984, p. 420
- 5 Scriven, E.F.V. and Turnbull, K., Chem. Rev., 1988, 88: 297
- 6 Kumar, H.M.S., Reddy, B.V.S., Anjaneyulu, S. and Yadav, J.S., Tetrahedron Lett., 1999, 40: 8305
- 7 Brase, S., Gil, C., Knepper, K. and Zimmerman, V., Angew. Chem. Int. Ed., 2005, 44: 5188
- 8 Valiaeva, N., Bartley, D., Kono, T. and Coward, J.K., J. Org. Chem., 2001, 66: 5146
- 9 Mallakpour, S. and Nasr-Isfahani, H., Indian J. Chem. 41B., 2002, 169
- 10 Wang, Y.G., Wang, Z.Y., Zhao, X.Y. and Song, X., Chem. Abstr., 2005, 143: 326296c
- 11 Laszlo, P. and Polla, E., Tetrahedron Lett., 1984, 25: 3701
- 12 Van Reijendam, J.W. and Baardman, F., Synthesis, 1973, 413
- 13 Erthardt, P.W., J. Org. Chem., 1979, 44: 883
- 14 Pfister, J.R. and Wymann, W.E., Synthesis, 1983, 38
- 15 Padwa, A., Brodney, M.A., Liu, B., Satake, K. and Wu, T., J. Org. Chem., 1999, 64: 3595
- 16 Chorev, M., Donald, M.S.A. and Goodman, M., J. Org. Chem., 1984, 49: 821
- 17 Kobagashi, S., Kamiyama, K., Iimori, T. and Ohno, M., Tetrahedron Lett., 1984, 25: 2557
- 18 Kuramochi, K., Watanabe, H. and Kitahara, T., Synlett, 2000, 397
- 19 Stefanuti, I., Smith, S.A. and Taylor, R.J.K., Tetrahedron Lett., 2000, 41: 3735
- 20 Bolm, C., Dinter, C.L., Schiffers, I. and Defrere, L., Synlett, 2001, 1875
- 21 Arrieta, A., Aizpurua, J.M. and Palomo, C., Tetrahedron Lett., 1984, 25: 3365
- 22 Canon, P., Akssira, M., Dahouh, A., Kashmi, H. and Boumzebrra, M., Heterocycles, 1993, 36: 1305
- 23 Shao, H., Colucci, M., Tong, S., Zhang, H. and Castelhano, A.L., Tetrahedron lett., 1998, 39: 7235
- 24 Froeyen P., Phosphorus, Sulfur Silicon Relat. Elem., 1994, 89: 57
- 25 Gumsate, V.K., Bhawal, B.M. and Deshmukh, A.R.A.S., Tetrahedron Lett., 2002, 43: 1345
- 26 Bandgar, B.P. and Pandit, S.S., Tetrahedron Lett., 2002, 43: 3413
- 27 Lee, J.G. and Kwak, K.H., Tetrahedron Lett., 1992, 33: 3156
- 28 Elmorsy, S.S., Tetrahedron Lett., 1995, 36: 1341

- 29 Bose, D.S. and Reddy, A.V.N., *Tetrahedron Lett.*, 2003, 44: 3543
- 30 Arote, N.D. and Akamanchi, K.G., *Tetrahedron Lett.*, 2007, 48: 5661
- 31 Marinescu, L., Thinggaard, J., Thomsen, I.B. and Bols, M., *J. Org. Chem.*, 2003, 68: 9453
- 32 Sherrington, D.C. and Hodge, P., "Synthesis and separations using functional polymers", John Wiley and Sons, New York, 1988
- 33 Takemoto, K., Inaki, Y. and Ottenbrite, R.M., "Functional monomers and polymers", Marcel Dekker Inc., New York, 1987
- 34 Ley, S.V., Baxendale, I.R., Bream, R.N., Jackson, P.S., Leach, A.G., Longbottom, D.A., Nesi, M., Scott, J.S., Storer, R.I. and Taylor, S., *J. Chem. Soc. Perkin Trans I*, 2000, 3815
- 35 Karimi Zarchi, M.A. and Escandari, Z., *J. Appl. Polym. Sci.*, 2011, 121: 19116
- 36 Karimi Zarchi, M.A. and Nazem, F., *J. Appl. Polym. Sci.*, 2012, 123: 1977
- 37 Karimi Zarchi, M.A., Nabaei, R. and S. Barani, *J. Appl. Polym. Sci.*, 2012, 123: 788
- 38 Karimi Zarchi, M.A., Nabaei, R., *J. Appl. Polym. Sci.*, 2012, 124: 2362
- 39 Lu, Y. and Taylor, R.T., *Tetrahedron Lett.*, 2003, 44: 9267
- 40 Marinescu, L.G., Pedersen, C.M. and Bols, M., *Tetrahedron*, 2005, 61: 123
- 41 Bellamy, L.J., "The infrared spectra of complex molecules", Methuen and Co., Ltd., London, 1985
- 42 Lieber, E. and Oftedahl, E., *J. Org. Chem.*, 1959, 24: 1014
- 43 Tale, R.H. and Patil, K.M., *Tetrahedron Lett.*, 2002, 43: 9715
- 44 Turro, N.J., *Tetrahedron*, 1987, 43: 1589