doi:10.1246/cl.2011.1149
Published on the web September 28, 2011

Silicon-mediated Direct Conversion of Acyl Chlorides to Carbamoyl Azides or/and Tetrazolinones under Mild Conditions

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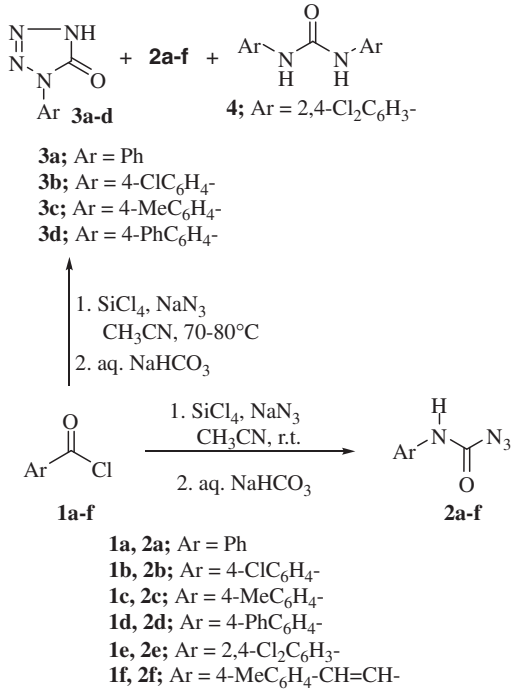
A simple and mild one-pot procedure for the synthesis of carbamoyl azides from acyl chlorides utilizing a combination of tetrachlorosilane and sodium azide in acetonitrile at ambient temperature is reported. Under gentle heating, 1-aryltetrazolin-5-ones were also obtained in one-pot process presumably via a [3 + 2] cycloaddition step.

Carbamoyl azides are useful organic compounds having wide applications in organic synthesis as well as in industry.[1] They are used as key intermediates for synthesis of various heterocyclic[2] and medicinally important compounds.[3] The conventional methods for the preparation of carbamoyl azides generally includes addition of azide species such as hydrazoic acids[4] or triarylbismuth diazides[5] to isocyanates, nitrosation of semicarbazides,[6] and oxidation of aldehydes with pyridinium chlorochromate[7] or iodobenzene dichloride[8] in the presence of sodium azide. Aldehydes have been converted into carbamoyl azides by using iodine azide either under reflux[9] or under continuous flow reaction conditions in microreactors.[10] Carbamoyl azides can also be prepared from tertiary amines using triphosgene and sodium azide,[11] from primary amines and carbon dioxide with tetramethylphenylguanidine and diphenylphosphoryl azide,[12] or from carboxylic acids by means of the Vilsmeier salt prepared from phosgene and DMF[13] or by adding PPh_3/NCS and then $NaN_3/Me_3N{\cdot}HCl$.[14] On the other hand, tetrazolinone derivatives have gained intense interest due to their applications in medicine[15] and agriculture.[16] Isocyanates represent in many cases the precursors for many tetrazolone derivatives through their reaction with an azide source.[17]

Silyl azides particularly, trimethylsilyl azide ($TMSN_3$)[18] react with some carboxylic acid chlorides,[19] anhydrides,[20] esters, and lactones[21] to provide a facile synthetic route to a variety of isocyanates, which in some cases directly cyclize to heterocyclic compounds. A combination of tetrachlorosilane ($SiCl_4$) and sodium azide have been used for the conversion of aldehydes to the corresponding nitriles,[22] or to acyl azides in the presence of MnO_2.[23] Ketones,[24] including α,β-unsaturated ketones,[25] β-chloroketones,[26] and carboxylic acid amides[27] were converted to the corresponding tetrazoles utilizing this combination.

As a part of investigation of reactivity and potentiality of this in situ reagent which provides an expedient source of azide and in conjunction with our interest in exploring the utility of in situ reagents based on tetrachlorosilane (TCS)[28] in organic synthesis, we report herein a facile and mild procedure for the synthesis of carbamoyl azides through the reaction of carboxylic acid chlorides with the inexpensive and readily available tetrachlorosilane–sodium azide at room temperature. When the same mixtures were gently heated, 1-aryltetrazolin-5-ones were obtained as major products.



Scheme 1. Reaction of acyl chlorides with $SiCl_4$–NaN_3.

Stirring a mixture of carboxylic acid chloride (1 equiv) with a combination of $SiCl_4$ (2 equiv) and NaN_3 (6 equiv) in dry acetonitrile at room temperature affords the corresponding carbamoyl azides in good yields after simple aqueous work-up (Scheme 1 and Table 1). Identification of the carbamoyl azides was carried out by their spectroscopic analyses as well as by comparing their properties to those reported. Beside the –CO– stretching bands, each product exhibited new characteristic IR signals at 3269–3380 and 2146–2192 cm^{-1} for the –NH and $-N_3$ groups respectively. To improve our procedure for a time-saving reaction, we carried out the reaction under gentle heating. Thus, stirring a mixture of benzoyl chloride with $SiCl_4$–NaN_3 in acetonitrile at 70–80 °C gave 1-phenyltetrazolin-5-one as a major product, in addition to the expected phenylcarbamoyl azide. Monitoring the reaction with TLC showed a complete disappearance of the starting material within 2 h. This result led us to investigate the reactions under gentle heating as a one-pot process to tetrazolinones. Thus, various carboxylic acid chlorides were reacted with $SiCl_4$–NaN_3 at 70–80 °C to give the respective carbamoyl azides as minor products as well as the tetrazolinone derivatives as major products in most cases (Scheme 1 and Table 1).

The structure of tetrazolinone derivatives was assigned based on their spectral analyses as well as by matching their melting points with reported literature.[17] For example, compounds **3a** and **3b** showed carbonyl stretching absorption in the IR spectra at ν/cm^{-1} 1713 and 1720 as well as the NH stretching at 3279 and 3213, respectively. The ^{1}H NMR spectra of compound **3a** revealed the presence of a broad singlet for NH at δ 14.6. Furthermore, its mass spectrum displayed the m/z 162 peak corresponding in mass to the molecular ion (M^+) of compound **3a** as the base peak. Fragmentation of the tetrazolinone ring gives an intense peak at m/z 119, which provides evidence for cycloreversion[29] with formation of $[PhNCO]^+$ (probably including $[PhN_3]^+$). Both these later radical ions fragment, by loss of 28 mass units, giving the appropriate phenyl nitrenium ion $[PhN]^+$(m/z 91).[19]

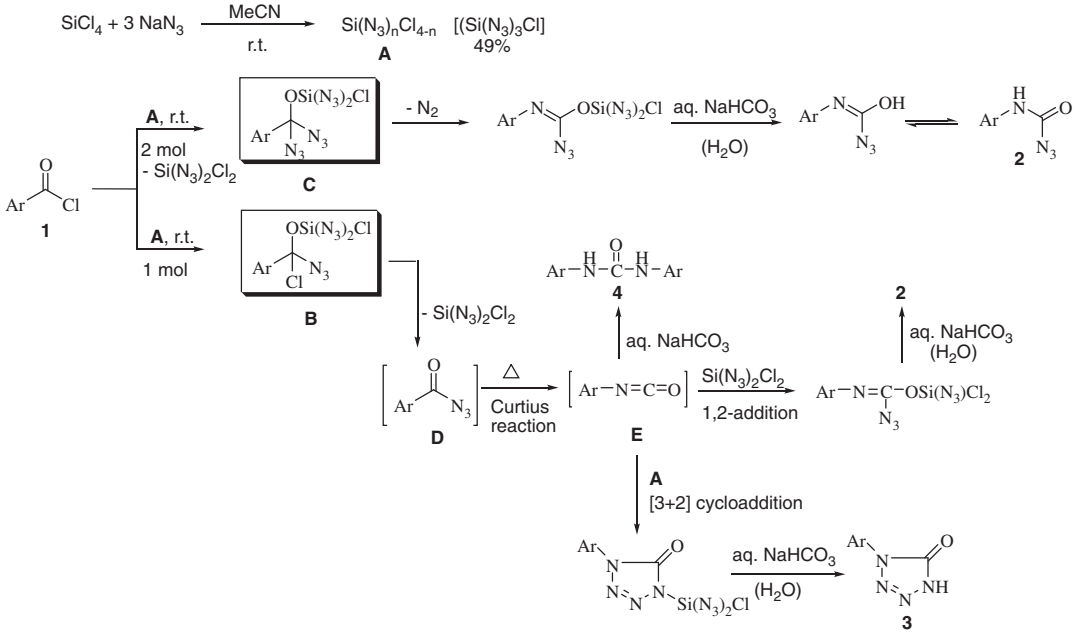
Table 1. Reaction of acyl chlorides with $SiCl_4$–NaN_3 combination

Entry	Substrate	Temp /°C	Time /h	Product	Yield /%[a]
1	**1a**	r.t.	12	**2a**	84
2	**1a**	70–80	2	**2a**, **3a**	26, 72
3	**1b**	r.t.	13	**2b**	77
4	**1b**	70–80	3	**2b**, **3b**	31, 67
5	**1c**	r.t.	14	**2c**	81
6	**1c**	70–80	3	**2c**, **3c**	22, 75
7	**1d**	r.t.	12	**2d**	78
8	**1d**	70–80	4	**2d**, **3d**	24, 70
9	**1e**	r.t.	16	**2e**	88
10	**1e**	70–80	5	**2e**, **4**	78, 19
11	**1f**	r.t.	22	**2f**	63
12	**1f**	70–80	7	**2f**	67
13	Acetyl chloride	r.t. 70–80	22 15	—	—

[a]Isolated yield.

The generality of the process was examined through applying the reaction to various aromatic acid chlorides. The reaction tolerated several functional groups on the aromatic ring, including chlorine, methyl, and phenyl (Table 1). Sterically hindered acid chlorides such as 2′,4′-dichlorobenzoyl chloride as well as α,β-unsaturated acid chlorides such as 4′-methylcinnamoyl chloride gave the corresponding carbamoyl azides as major products either at room temperature or under heating for prolonged time even when using an excess reagent (Table 1, Entries 9–12). Unfortunately, the reaction failed with aliphatic acid chlorides. For example, acetyl chloride hardly gave a minute amount of dimethyl urea and no other distinct products were observed under the reaction conditions (Entry 13, Table 1).

A plausible pathway for the present reaction is depicted in Scheme 2. It is likely that the carbamoyl azides **2** are formed at room temperature via addition of two moles of the silicon azide chloride **A**, which was generated as a major triazidochlorosilane from the reaction of $SiCl_4$ and NaN_3 in a molar ratio 1:3[30] to the carbonyl group of **1**. The reaction involves the formation of the *gem*-diazide **C** which undergoes a Schmidt type rearrangement[31] giving **2** after an aqueous work-up. Under gentle heating, an alternative pathway may operate; formation of the siloxy azide intermediate **B** in a similar 1,2-addition step of one mole of **A** to **1**. **B** gives carbonyl azide **D**, which undergoes a Curtius reaction to form the intermediate isocyanate **E**. Subsequent addition of a second mole of **A** to **E** gives 1-aryltetrazolin-5-one **3** or carbamoyl azide **2** via [3 + 2] cycloaddition or 1,2-addition, respectively after aqueous work-up. Isolation of diarylurea **4** (Entry 10) after aqueous work-up indicates the formation of aryl isocyanate through the reaction pathway. Moreover, carbamoyl azides have proved resistant to both Curtius rearrangement[32] and base-induced cyclization to tetrazole derivatives.[33] On the basis



Scheme 2. Plausible mechanism for the formation of **2**, **3**, and **4**.

of these considerations, it seems that the cyclization of carbamoyl azides to the terazolinone **3** is not a pluasible pathway.

In conclusion, we have developed a new practical and efficient route to carbamoyl azides as well to 1-aryltetrazolinone derivatives from acyl chlorides utilizing the cheap and readily available tetrachlorosilane and sodium azide.[34] The mild reaction conditions, easy work-up procedure and simple operation are advantages of this procedure. Moreover, the present method provides an additional application of the in situ generated $SiCl_4/NaN_3$ which represents a safer substitute to the volatile and highly toxic hydrazoic acid as well as to the relatively expensive $TMSN_3$.

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34 *Typical procedure for the synthesis of arylcarbamoyl azides or/and 1-aryltetrazolinones*: To a mixture of acid chloride (5 mmol) and NaN_3 (30 mmol) in CH_3CN (20 mL), $SiCl_4$ (10 mmol) was added and the reaction mixture was stirred at room temperature or under heating at 60–70 °C. On completion (the reaction was monitored by TLC), the mixture was quenched with cold $NaHCO_3$ (aq), extracted with CH_3COOEt, dried over anhydrous $MgSO_4$ and the solvent was evaporated under vacuum and the residue was chromatographed using petroleum ether–ethyl acetate (5:1) as the eluent system to give pure **2** or **2** and **3** or **4** respectively. Data for some representative examples are listed below:

2,4-Dichlorophenylcarbamoyl azide (2e): mp 121 °C; IR (KBr): $\nu = 3269$ (NH), 2920, 2851, 2192, 2148 (–N_3), 1681 (C=O), 1527 (N–C=O), 1472, 1383, 1253, 1237, 1101, 1053, 974, 789, 732, 664 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.43 (s, 1H), 7.37 (d, $J = 8.9$ Hz, 1H), 7.23 (d, $J = 8.9$ Hz, 1H), 6.81 (s, 1H, NH); ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.1, 136.7, 133.8, 133.3, 129.4, 129.1, 127.3; Anal. Calcd for $C_7H_4Cl_2N_4O$ (231.04): C, 36.39; H, 1.75; N, 24.25%. Found: C, 36.18; H, 1.82; N, 24.13%.

2-(4-Methylphenyl)vinylcarbamoyl azide (2f): mp 154 °C; IR (KBr): $\nu = 3380$ (NH), 2933, 2149 (–N_3), 1688 (C=O), 1606 (C=C), 1511 (N–C=O), 1462, 1380, 1341, 1295, 1250, 1177, 1113, 1030, 830 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 7.72 (d, $J =$ 15.8 Hz, 1H), 7.43 (d, $J = 8.1$ Hz, 2H), 7.20 (d, $J = 8.1$ Hz, 2H), 6.95 (s, 1H), 6.38 (d, $J = 15.8$ Hz, 1H), 2.35 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 157.1, 146.7, 141.8, 131.1, 129.8, 128.6, 116.3, 22.1; Anal. Calcd for $C_{10}H_{10}N_4O$ (202.21): C, 59.40; H, 4.98; N, 27.71%. Found: C, 59.61; H, 5.13; N, 27.58%.

1-Phenyl-2-tetrazolin-5-one (3a): mp 189–190 °C (lit.[17c] mp 192–193 °C); $R_f = 0.68$, petroleum ether (60–80 °C)–ethyl acetate: 3/1; IR (KBr plate): $\nu = 3279$ (NH), 1713 (C=O), 1605 (C=C), 1499, 1387, 1349, 1294, 1238, 1056, 969, 754, 687, 653 cm^{-1}. ^1H NMR (300 MHz, DMSO-d_6): δ 14.6 (br, 1H, NH), 7.86 (d, $J = 8$ Hz, 2H), 7.55 (m, 2H), 7.44 (m, 1H); MS (m/z, %): 162 (M^+, 100), 163 ($M^+ + 1$, 22), 119 ($M^+ - HN_3$ or HNCO, 81), 91 (37), 77 (32).

1-(4-Methylphenyl)-2-tetrazolin-5-one (3c): mp 183–185 °C (lit.[17b] mp 183.5–184.5 °C); $R_f = 0.67$, petroleum ether (60–80 °C)–ethyl acetate: 3/1; IR (KBr plate): $\nu = 3198$ (NH), 2920, 1706 (C=O), 1605 (C=C), 1549, 1512, 1371, 1310, 1208, 1125, 1078, 920, 813, 738 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6): δ 8.50 (s, 1H), 7.33 (d, $J = 8.4$ Hz, 2H), 7.06 (d, $J = 8.4$ Hz, 2H), 2.24 (s, 3H); MS (m/z, %): 176 (M^+, 17), 133 ($M^+ - HN_3$ or HNCO, 100), 106 (21), 104 (61), 91 (23), 78 (26).

1-(4-Biphenylyl)-2-tetrazolin-5-one (3d): mp 203–205 °C; $R_f =$ 0.45, petroleum ether (60–80 °C)–ethyl acetate: 3/1; IR (KBr plate): $\nu = 3269$ (NH), 1647 (C=O), 1600 (C=C), 1532 (N–C=O), 1492, 1398, 1325, 1283, 1089, 1013, 824, 754, 653 cm^{-1}. ^1H NMR (300 MHz, DMSO-d_6): δ 10.49 (s, 1H), 7.98 (d, $J = 8.4$ Hz, 2H), 7.81 (d, $J = 8.4$ Hz, 2H), 7.62 (m, 2H), 7.42 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 164.51, 137.95, 136.56, 133.36, 129.66, 128.57, 128.51, 127.42, 121.88; Anal. Calcd for $C_{13}H_{10}N_4O$ (238.24): C, 65.54; H, 4.23; N, 23.52%. Found: C, 65.24; H, 4.58; N, 23.89%.

