High-yield synthesis and characterisation of a potential chelating agent 2,4,6-triamino-1,3,5-triazine-N,N,N',N',N'',N''-hexaacetic acid

Xiaobin Wang[a], Xia Meng[b], Hongdong Duan[a]*, Dawei Qin[a] and Xingang Wang[a]

[a]*School of Chemical Engineering, Shandong Institute of Light Industry, Jinan 250353, P. R. China*

[b]*School of Light Chemistry and Environment Engineering, Shandong Institute of Light Industry, Jinan 250353, P. R. China*

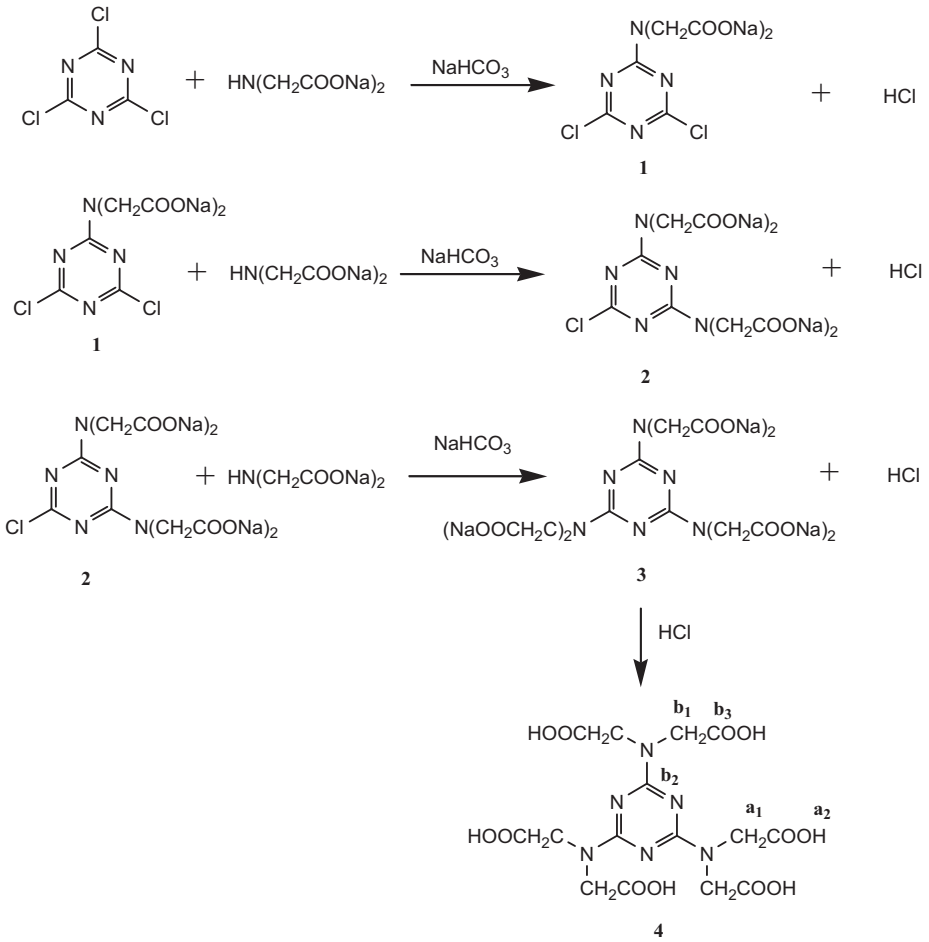
A useful and potential chelating agent, 2,4,6-triamino-1,3,5-triazine-N,N,N',N',N'',N''-hexaacetic acid (melamine hexaacetic acid), was synthesised by nucleophilic substitution through three steps and its structure was confirmed by IR, ^{1}H NMR, ^{13}C NMR and elemental analyses. The chelation value of melamine hexaacetic acid was determined, by calcium oxalate titration. In comparison with EDTA, melamine hexaacetic acid has better chelating ability.

Keywords: chelating agent, 2,4,6-triamino-1,3,5-triazine-N,N,N',N',N'',N''-hexaacetic acid, chelation value, chelating ability

Currently important in coordination chemistry is the synthesis of ligands and complexes of distinctive structures and novel functions by simple methods. Polyaminocarboxylic ligands, such as EDTA, DTPA, NTA, and TTHA are used widely in many fields, including medicine, analytical chemistry, metal coordination chemistry, and so on. They form stable complexes with many kinds of metal cations, but such stability is relative. Complexes may decompose by heat, by change of pH and other variations of conditions, so potential chelating agents of proven high chelating ability are constantly being sought.

2,4,6-triamino-1,3,5-triazine-N,N,N',N',N'',N''-hexaacetic acid (melamine hexaacetic acid), prepared in this paper, is a triazine derivative. Triazine derivatives, because of their good chemical stability, have been widely used in many fields. Moreover, melamine hexaacetic acid is also a polyaminocarboxylic ligand, which can provide six nitrogen atoms and six oxygen atoms (Scheme 1, compound **4**) to coordinate with metal ions and form stable complexes. As a potential ligand and multi-functional monmer, melamine hexaacetic acid has recently evoked a lot of interest.

The stability constants of lead (II), copper (II), arsenic (V) and titanium (IV) with melamine hexaacetic acid have been obtained, but the preparation of melamine hexaacetic acid was not reported.[1,2] Recently, Nelson *et al*. reported the preparation of melamine hexaacetic acid with cyanuric



Scheme 1 The mechanism of synthesis of compound **4.**

* Correspondent. E-mail: hdduan@163.com

chloride and iminodiacetonitrile and used it as an intermediate for the synthesis of light stabilisers for plastics.[3] Although Conrow and Bernstein[4] have reported the preparation of melamine hexaacetic acid with cyanuric chloride and iminodiacetic acid disodium salt monohydrate in one step, the method had some disadvantages. The reaction conditions were not controlled well and the yield was very low. A better method must be found to solve these problems. There also is no reported characterisation of the structure of melamine hexaacetic acid and determination of its chelation value.

In this paper, melamine hexaacetic acid has been synthesised in three steps by nucleophilic substitution of cyanuric chloride and iminodiacetic acid disodium salt monohydrate. The synthetic mechanism and structure of the ligand are outlined in Scheme 1. The reaction conditions are moderate, raw materials are easily obtained, and the yield is high. The chelation value of melamine hexaacetic acid has been determined by the method of calcium oxalate titration, and the results indicate that melamine hexaacetic acid had good chelating ability.

Experimental

Materials and methods

Cyanuric chloride and iminodiacetic acid disodium, all industrial grade, were purchased from Hebei Chengxin Limited Cooperation and Nantong Guangrong Chemicals, respectively; sodium bicarbonate and hydrochloric acid, all A.R, were products of Zibo Chemicals and Laiyang Chemicals of Shandong Province, China. All these chemicals were used as received without further treatment. Hexasodium melamine hexaacetate was made by ourselves.

IR spectra were recorded on a Bruker TENSOR 27 FT-IR spectrometer. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker AVENCE 400 spectrometer with DMSO-d_6 as solvent and tetramethylsilane (TMS, δ = 0 ppm) as internal standard. Elemental analyses were performed by Elementar vario EL III element analyser.

Synthesis of 2,4,6-triamino-1,3,5-triazine-N,N,N',N'',N''-hexaacetic acid

To a stirred solution of cyanuric chloride (3.7 g, 0.02 mol) in acetone (25 ml) was added a solution of iminodiacetic acid disodium salt monohydrate (3.54 g, 0.02 mol) and sodium bicarbonate (1.68 g, 0.02 mol) in water (150 ml) at 0–5°C. The solution was stirred at 0–5°C for 2 hours. Then a mixed powder of iminodiacetic acid disodium salt monohydrate and sodium bicarbonate was added to the solution above. The solution was stirred at 45°C for 3.5 h. Finally, the same mixed powder was added to above system again. The solution was stirred at 95°C for 5 h, boiled to remove acetone, and refluxed for 16 h and compound **3** was prepared. The resulting colourless solution was concentrated to 100 ml, filtered, acidified to pH 1–1.5 with 20 ml of concentrated hydrochloric acid and allowed to crystallise. The product was collected by filtration, washed with a small amount of ethanol and ether, recrystallised, and dried by conventional means to obtain melamine hexaacetic acid (compound **4**) as colourless crystals (6.5 g, 69%). M.p. 244–246°C (literature value[4] 246–249°C).

The determination of chelation value

Chelation value is a standard, which can measure a chelating agent's efficiency. It is usually expressed by the calcium chelation value (CV),

$$CV = \frac{m_{CaCO_3} / mg}{m_C / g} \quad (1)$$

Where m_{CaCO3} is the chelated mass of $CaCO_3$ and m_C is the spent mass of chelating agent, in equation (1).

The method of calcium oxalate titration was used to determine the chelation value of melamine hexaacetic acid. This method was previously described.[5] Because of its good water-solubility, hexasodium melamine hexaacetate, made by ourselves, was used to determine chelation value.

Results and discussion

2,4,6-triamino-1,3,5-triazine-N,N,N',N',N'',N''-hexaacetic acid (compound **4)** was prepared via nucleophilic substitution reaction as depicted in Scheme 1. The preparation included three steps, the first was facile. Because the activity of the chlorine atoms of cyanuric chloride would reduce after the first step, the reaction conditions of second and third step were strengthened. In addition, the chlorine atoms of cyanuric chloride are easy to hydrolyse, so control of pH and reaction temperature was key. After repeated experiments, the best reaction conditions found are as described in this paper.

In comparison with the spectra of the reacting materials, the IR spectra of compound **4** exhibited the following characteristics: (1) complete disappearance of C–Cl and N–H vibrations; (2) a peak assigned to stretching vibration of $–CH_2$ at 2926 cm^{-1}; (3) the presence of υ (C=O) was strongly supported by the band at 1732 cm^{-1}; (4) strong peaks assigned to the triazine ring at 1564, 1393, and 811 cm^{-1}; (5) other important peaks were observed, *i.e.* -CH_2 bending vibration at 1492 cm^{-1} and C–N stretch vibration at 1258 cm^{-1}.

Hydrogen and carbon atoms of similar chemical environment in **4** are labeled as $\mathbf{a_1}$, $\mathbf{a_2}$ and $\mathbf{b_1}$, $\mathbf{b_2}$, $\mathbf{b_3}$, respectively (Scheme 1, compound **4**). Corresponding peak assignments and characteristics for ^{1}H NMR and ^{13}C NMR were as follows. ^{1}H NMR (DMSO-d_6, 400 MHz, δppm): 12.445 (s, 6 H, –COOH), 4.080 (s, 12 H, $–CH_2–$): ^{13}C NMR (DMSO-d_6, 400 MHz, δppm): 171.781 (–COOH), 165.100 (C–N), 49.231 ($–CH_2–$).

Although melamine hexaacetic acid has 18 hydrogen atoms, it only had two kinds of hydrogen atoms which belong to methylene ($\mathbf{a_1}$) and carboxyl ($\mathbf{a_2}$), respectively. There were only two groups of peaks, which were agreed well with the structure of compound **4**. Melamine hexaacetic acid has 15 carbon atoms of three types ($\mathbf{b_1}$, $\mathbf{b_2}$, $\mathbf{b_3}$). There are three groups of peaks, which also agrees well with the structure of compound **4**. The data obtained from ^{1}H and ^{13}C NMR spectra strongly supported the structure of compound **4**.

Elemental analyses for melamine hexaacetic acid ($C_{15}H_{18}N_6O_{12}$): calculated: C 38.0, H 3.8, N 17.7, found: C 37.7, H 3.9, N 17.5%.

Chelation value

The chelation value of melamine hexaacetic acid was determined as 280 mg $CaCO_3$/g (hexasodium melamine hexaacetate), by the method previously described in the literature and equation (1). The chelation value of EDTA is 260 mg $CaCO_3$/g (ethylene diamine tetraacetic acid tetrasodium).[6] This indicates that melamine hexaacetic acid has the better chelating ability, probably because of the nitrogen atoms of the triazine ring.

Conclusion

In this paper, a useful chelating agent, 2,4,6-triamino-1,3,5-triazine-N,N,N',N',N'',N''-hexaacetic acid, was synthesised, and its structure was characterised by IR, ^{1}H NMR, ^{13}C NMR and elemental analyses. It was proved that 2,4,6-triamino-1,3,5-triazine-N,N,N',N',N'',N''-hexaacetic acid has good chelating ability.

The authors are grateful for the financial support of the Natural Science Foundation of Shandong Province (No. Y2005B22(Y2007B38).

Received 26 July 2007; accepted 10 October 2007
Paper 07/4763 doi: 10.3184/030823407X264263

References

1 R.P. Lastovskii, N.M. Dyatlova, I.D. Kolpakova, V. Ya. Temkina and O. Yu. Lavrova, *Acta. Chem*., 1962, **32**, 229.
2 R.P. Lastovskii, N.M. Dyatlova, V. Ya. Temkina, I.D. Kolpakova and O. Yu. Lavrova, *Anal. Chem*, 1962, **62**, 165.
3 R.V. Nelson, and J.F. Stephen, US Patent 4,883,831(Nov. 28, 1989).
4 R.B. Conrow and S. Bernstein, US Patent 4,183,929 (Jan. 15, 1980).
5 H.Y. Xu. Master's Degree Dissertation of Beijing University of Chemical Technology, 2004.
6 C.Z. Liao. Master's Degree Dissertation of Nanjing University of Science and Technology, 2005.