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The development and amino acid binding ability of nano-materials based on azo derivatives: Theory and experiment

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ABSTRACT

Two nano-material-containing azo groups have been designed and developed, and the binding ability of nano-materials with various amino acids has been characterized by UV–vis and fluorescence titrations. Results indicated that two nano-materials showed the strongest binding ability for homocysteine among twenty normal kinds of amino acids (alanine, valine, leucine, isoleucine, methionine, aspartic acid, glutamic acid, arginine, glycine, serine, threonine, asparagine, phenylalanine, histidine, tryptophan, proline, lysine, glutamine, tyrosine and homocysteine). The reason for the high sensitivity for homocysteine was that two nano-materials containing an aldehyde group reacted with –SH in homocysteine and afforded very stable thiazolidine derivatives. Theoretical investigation further illustrated the possible binding mode in host–guest interaction and the roles of molecular frontier orbitals in molecular interplay. Thus, the two nano-materials can be used as optical sensors for the detection of homocysteine.

1. Introduction

In recent years, increasing attention in the field of host–guest chemistry has been devoted to the fast development of the molecular recognition system [1–3]. The assay of amino acid is of particular importance in different food, biological and chemical samples [4,5]. Detection of amino acids has paramount importance as they form the fundamental units of all the life forms. The design and recognition properties of artificial receptors for amino acids have attracted extensive interest [6–8]. Due to the complex matrices often encountered, analytical methods for amino acid determination mainly rely on the separation processes using liquid chromatography or capillary electrophoresis [9]. Such methodologies do not lend themselves to rapid analysis, as might be required in industrial processes. As an important amino acid, cysteine plays a crucial role in living systems [10,11]. The deficiency of cysteine is associated with slowed growth, hair depigmentation, edema, lethargy, liver damage, muscle and fat loss, skin lesions, and weakness [12]. Detection methods for cysteine have been reported [13,14] based on traditional determination. Recently, reports of inorganic and polymer nano-materials are numerous. However, research about small organic nano-material is few [15,16] and there are few reports about its application on the detection of amino acid.

Bearing the above considerations, herein we synthesized two azo derivatives involving hydroxyl groups (Scheme 1) and developed their nano-materials. The detection of amino acid using two nano-materials was also studied in a neutral aqueous solution. Results indicated that these nano-materials showed the strongest binding ability toward homocysteine among amino acids tested (alanine, valine, leucine, isoleucine, methionine, aspartic acid, glutamic acid, arginine, glycine, serine, threonine, asparagine, phenylalanine, histidine, tryptophan, proline, lysine, glutamine, tyrosine and homocysteine).

2. Experimental

2.1. Reagents and solutions

Most of the starting materials were obtained commercially and all reagents and solvents used were of analytical grade. All amino acids were purchased from Aladdin Chemistry Co. Ltd. (Shanghai, China), and stored in a desiccator under vacuum, and used without any further purification. Dimethyl sulfoxide (DMSO) was distilled in vacuum after being dried with CaH_2. C, H and N elemental analyses were made on a Vanio-EL instrument. ^1H NMR spectra were recorded on a Unity Plus-400-MHz spectrometer. ESI–MS was performed with a Mariner apparatus. UV–vis titration experiments were made on a Shimadzu UV2550 spectrophotometer at 298 K. The binding constant, K_s, was obtained by non-linear least square calculation method for data fitting.

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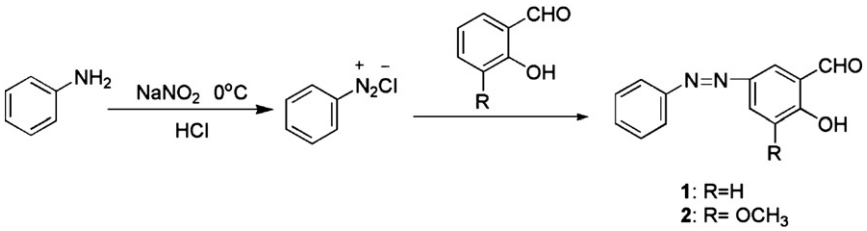

Scheme 1. Synthesis route for compounds **1** and **2.**

2.2. Synthesis of compounds *1* and *2*

Compounds **1** and **2** were synthesized according to the route shown in Scheme 1.

2.2.1. 5-Phenylazo-salicylaldehyde (*1*)

5-Phenylazo-salicylaldehyde was synthesized according to the literature [17]. HCl (37%, 6 mL) was added slowly to a solution of aniline (0.05 mol, 5 mL) in a small quantity of water at 0–5 °C. Then, $NaNO_2$ (20%, 20 mL) was added to the above-mentioned mixture and the solution was stirred for 1 h to give a bright yellow solution. Salicylaldehyde (0.05 mol) dissolved in the solution of Na_2CO_3 (18 g Na_2CO_3 and 150 mL H_2O) was added dropwise to the bright yellow solution for 1 h. After stirring for 4 h, the reaction mixture was neutralized with HCl. The brown crude solid was filtered and recrystallized from ethanol to afford a pure product. Yield: 82%; mp: 120 °C; and ^{1}H NMR (400 MHz, DMSO-d_6, 298 K) δ 11.93 (s, ^{1}H, −OH), 10.17 (s, ^{1}H, −CHO), 8.03 (s, ^{1}H, pH-H), 7.94 (s, 2H, pH-H), 7.88 (s, ^{1}H, pH-H), 7.61–7.52 (m, 3H, pH-H) and 7.12 (s, ^{1}H, pH-H). Elemental analysis: Calc. for $C_{13}H_{10}N_2O_2$: C, 69.02; H, 4.46; and N, 12.38; and found: C, 68.91; H, 4.66; and N, 12.54. ESI–MS (m/z): 225.2 $(M\text{-}H)^-$.

2.2.2. 5-Phenylazo-3-oxyl-salicylaldehyde (*2*)

The synthesis method was similar to the procedure above. Yield: 79%; ^{1}H NMR (400 MHz, DMSO-d_6, 298 K) δ 11.58 (s, ^{1}H, −OH), 10.04 (s, ^{1}H, −CHO), 7.92–7.90 (d, 3H, pH-H), 7.76 (s, ^{1}H, pH-H), 7.55–7.49 (m, 3H, pH-H) and 4.03 (s, 3H, $-CH_3$). Elemental analysis: Calc. for $C_{14}H_{12}N_2O_3$: C, 65.62; H, 4.72; and N, 10.93; and found: C, 65.44; H,4.37; and N, 11.19. ESI–MS (m/z): 255.3 $(M\text{-}H)^-$.

2.3. Preparation of two nano-materials

The nano-materials of compounds **1** and **2** were prepared by reprecipitation method [18,19]. The DMSO and the water solution of CTAB (hexadecyl trimethyl ammonium bromide) were a good solvent and a poor solvent, respectively. In the experiment, the good solvent containing compound **1** or **2** (0.35 mL, 4 mmol · L^{-1}) was poured into the poor solvent containing CTAB (100 mL, 3 mmol · L^{-1}). The mixture was placed for 48 h and centrifuged. The expected solid was washed with water and dried in vacuum.

3. Results and discussion

3.1. SEM images of two nano-materials

The SEM images were obtained by Quanta TM450 FEI, coating it with Au (Fig. 1). As shown in Fig. 1, compound **1** could be assembled into long-thin flakiness on the entire compound. The thickness of flakiness was in nanometer according to the scale. Compound **2**, formed into a rhombus. However, the size of flakiness was not very well-distributed, which may be related to the concentration of compound **2** and the selection of the poor solvent. The preparation of the nano-material for compound **2** with other concentrations and solvents was underway. The image of compound **1** was remarkably different from compound **2** due to the difference in substituent.

3.2. UV–vis titration

The binding ability of the two nano-materials with amino acid was investigated using UV–vis absorption spectra in DMSO–H_2O (1:1, v/v) at 298 K. In the absence of amino acid, nano-material **1** (4.0×10^{-5} mol · L^{-1} in DMSO) exhibited one obvious sharp peak at 340 nm with a weak absorption band at 425 nm (Fig. 2). Clear spectral changes were observed upon the addition of homocysteine to the solution of compound **1**. With the increase of homocysteine, the intensity of the absorption peak at 340 nm strengthened remarkably and the intensity of the weak absorption band slightly decreased. As a result, a hyperchromic effect occurred after compound **1** interacted with homocysteine. The clear isosbestic point appeared at 375 nm indicating the formation of thiazolinedine (Scheme 2, **1a**) [12]. When leucine, phenylalanine, alanine, glycine, valine, methionine, histidine, tryptophan, aspartic acid, glutamic acid, arginine and lysine were added to compound **1** respectively, the absorption spectra changed similarly to homocysteine which indicated that compound **1** also interacted with the above amino acids. However, no significant spectral changes were observed upon the addition

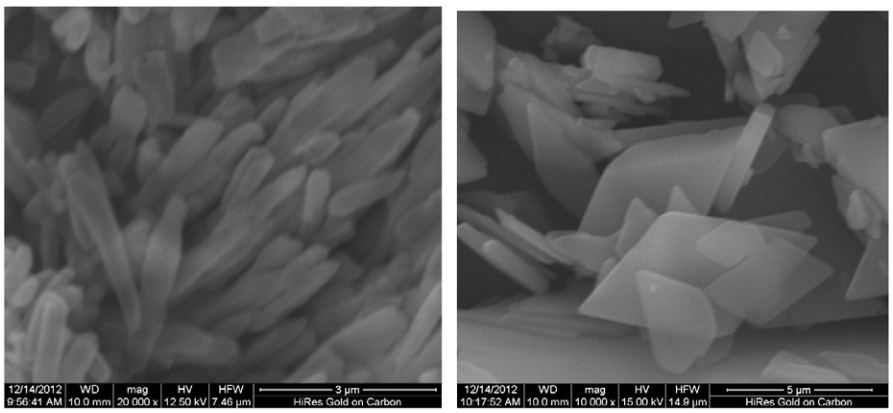

Fig. 1. SEM images for compounds **1** (left) and **2** (right).