Unexpected Formation of Dibenzophenazines†

Yoshio Kosugi,*,‡ Kazuo Itoho,§ Hiroshi Okazaki,|| and Tomoko Yanai||

Department of Applied Chemistry, School of Engineering, Nagoya University, 464-01 Nagoya, Department of Pharmaceutical Technology, Daiichi College of Pharmaceutical Sciences, 815 Fukuoka, and Analytical Section, Shinnikka Environmental Engineering Co. Ltd., 804 Tobata, Kitakyushu, Japan

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Introduction

During spectral and photochemical studies on arylazo compounds,[1] our attempts to prepare naphthylazo compounds by using iminodimagnesium dibromide reagents[2] were unsuccessful, but the unexpected formation of dibenzophenazines was discovered. In order to characterize this unexpected product, the reactions reported by Horner and Dehnert[3] and by Ullmann and Ankersmit[4] were carried out to obtain dibenzo[*a,h*]phenazine and dibenzo[*a,j*]phenazine, respectively. Surprisingly, both products were found to have the same spectral characteristics. In spite of being simple and symmetrical compounds, dibenzophenazines are not listed in common collective volumes for organic compounds.[5]

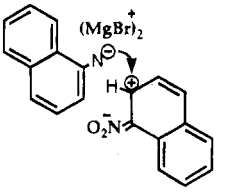
A new method for the preparation of the [*a,j*] isomer has not appeared in the literature in a long time. G. A. Russell and his co-workers[6] were the first to use *tert*-butoxide as a catalyst for the autoxidation of anilines, and the reaction has been extended to his famous semidione chemistry. The same reaction using aminonaphthalene in toluene yields dibenzo[*a,h*]phenazine.[3] Thus a base-catalyzed autoxidation of a combination of 1- and 2-aminonaphthalenes may give the [*a,j*] isomer (axial symmetry).

In this paper, the confusing situation arising from the unexpected formation of dibenzophenazines will be described, as well as the conclusive identification of two isomers by NMR spectroscopy. A sophisticated preparation of dibenzo[*a,j*]phenazine will also be presented.

Results and Discussion

A. Unexpected Formation of Dibenzophenazines. The reaction between aryliminodimagnesium dibromide (IDMg) and nitroarenes has been developed as a convenient preparation of azoarenes and azoxyarenes.[2] Utilizing this methodology, the reaction of 1-naphthyliminodimagnesium dibromide and 1-nitronaphthalene was carried out. However, the expected naphthylazo compounds were not obtained. Instead, the reaction gave dibenzo[*a,h*]phenazine as the product. Even under more favorable conditions for azo formation that result from changing the molar ratio of the IDMg reagent to 1-nitronaphthalene (0.2, 0.3, 1.0, 4, and 5), dibenzophenazine was the sole product.

The reaction is presumably initiated by the strong nucleophilic attack of the imino nitrogen at the 2-position, but not at the nitro group of the substrate. An intramolecular attack of the nitroxy ion on the 2-position of the IDMg naphthalene ring, followed by deoxygenations with excess IDMg reagent, will then result in the formation of a stable six-membered ring.



Alternatively, oxidations of azoxy intermediates may be involved. The formation of phenazine derivatives from 3-hydroxy-4-methylnitrobenzene[2d] is also explained by the mechanisms put forth for the present reaction.

An authentic sample was required to confirm the identity of the unexpected product from the IDMg reaction, and therefore, preparations of dibenzophenazines were investigated. Among a number of methods to prepare dibenzo[*a,h*]phenazine,[3,7] the Horner–Dehnert reaction is easily carried out with equipment in an ordinary laboratory.

On the other hand, Ullmann–Ankersmit's method was chosen to prepare another structural isomer, dibenzo[*a,j*]-phenazine.[4,7f,8] The reaction of 1-phenylazo-2-naphthylamine with 2-naphthol was carried out according to the literature procedure.[4] The spectral data of the product completely agree with those not only of the IDMg reaction but also of the Horner–Dehnert reaction described above. It has to be concluded that the Ullmann–Ankersmit reaction does not give the [*a,j*] isomer, but the [*a,h*] isomer.

The imino radical formed in the *tert*-butoxide-catalyzed autoxidation of 1-(or 2)aminonaphthalene in toluene intermolecularly attacks the 2-(or 1)position of the resonance hybrid of 1-(or 2)naphthylimino radicals and ultimately gives dibenzo[*a,h*]phenazine.[3] The same reaction conditions were applied to an equimolar mixture of 1- and 2-aminonaphthalenes. The [*a,j*] isomer was fortunately obtained as the major product with the [*a,h*] isomer as the minor product. A pair of 1- and 2-naphthylimino radicals is presumed to form a coupled intermediate whose amino group is more exposed to the base

† Dedicated to Professor Glen A. Russell on the occasion of his 70th birthday.

‡ Nagoya University.

§ Daiichi College of Pharmaceutical Sciences.

|| Shinnikka Environmental Engineering Co. Ltd.

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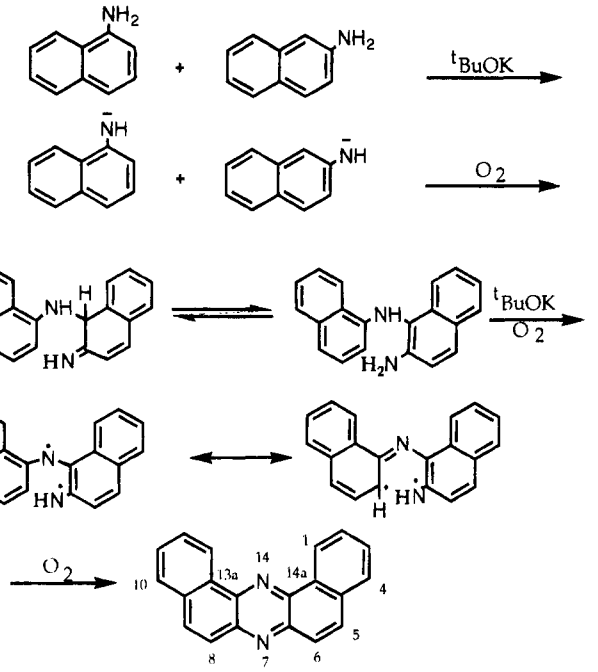
Scheme 1



and oxygen molecules in the second oxidative coupling, ultimately leading to the [*a,j*] isomer (Scheme 1).

The substitution of 1-(or 2)imino radical anion at the 1-(or 2)position of 2-(or 1)aminonaphthalene followed by base-catalyzed oxidation to the product is another plausible mechanism.[9]

B. The NMR Discrimination of the Isomers. Since differences in spectral data other than NMR are not observed among the isomers, including the [*a,c*] and [*a,i*],[10] the NMR spectral features are discussed with new assignments in light of our preliminary data.[11] The first remarkable feature is that proton peaks at chemical shifts as low (9.4–9.6 ppm) as aldehyde protons are observed. A peak at such a low field suggests an interaction with the lone pair electrons of the nitrogen atom. In support of this is the fact that H1 of the [*a,j*] isomer, wherein a greater interaction is expected, is at the lowest field (9.6 ppm). It is also well-known that the formation of a hydrogen bond causes the proton peak to shift to lower fields. Such downfield shifts are found in 1,7-phenanthroline and in acridines.[12] The effect on the carbon, C1 (124.9–126.2 ppm) is less prominent than it is in general.[13] The second feature is that significant downfield shifts of the H8 and H13 protons (8.88–8.98 ppm) are observed which are contrasted with that of the H6 proton (7.88 ppm) in the [*a,i*]. The chemical environments of protons H8 and H13, including hydrogen bonding, magnetic anisotropic effects, and electric field effects, seem practically equal to that of proton H6, but the bond orders with the nitrogen are larger by 25% (cf. supporting information). The correlation between bond order and chemical shift is discussed in C-13 NMR[14] where the paramagnetic term in Ramsey's equation[15] becomes a dominant factor. The bond order may also simply reflect the bonding nature in proton NMR.

Irradiation at H1 of the [*a,h*] isomer caused a significant NOE at H2 and a small one at H13 (not on H6), in spite of the fact that the bond distance between H1 and H13 is 4.07 Å. The result that two peaks were affected is good evidence for the [*a,h*] isomer, because the NOE can be observed at only one peak of H2 in the [*a,j*] isomer, where H1 and H13 are closer to each other (3.17 Å), and also isochronous. Another distinct difference is that the relaxation time (T_1) of H1 is 3.0 s for the [*a,j*] isomer and 5.1 s for the [*a,h*] isomer on a 400 MHz spectrometer.

While there are no compression effects[16] in the [*a,h*] and the [*a,j*] isomers, the compression effect on H4 and H5 (1.76 Å apart) in the [*a,c*] isomer allows for H4 and H5 to be assigned to the peak at 8.58 ppm. Total electron populations (Mulliken) calculated by the semiempirical MNDO PM3 method[17] are as follows: H1 (0.874) < H4 (0.887) (and H5) < H2 (0.893) (and H3, H6).

A more remarkable compression effect is observed with C-13 NMR: C4 resonates at 122.9 ppm in the [*a,c*] isomer at 123.0 ppm in 9,10-diaminophenanthrene, while the C1 signal of the four isomers is at 125–126 ppm. The electron populations of C1 (4.062) and C4 (4.109) are also in the same order as their chemical shifts (see Table 1 in the supporting information).

The unambiguous assignments, especially of H1, as well as the NOE and T_1 data, allow distinction between the [*a,h*], [*a,j*], and other two isomers.

Experimental Section

Dibenzo[*a,h*]phenazine. 1-Aminonaphthalene (17.9 g, 0.125 mol) dissolved in THF (100 mL) was added dropwise into a THF solution (50 mL) containing ethylmagnesium bromide, which was prepared with ethylbromide (27.25 g, 0.25 mol) and magnesium at below 10 °C. The exothermic reaction was kept at 40–60 °C under nitrogen atmosphere. After cooling to 40 °C, a THF (100 mL) solution of 1-nitronaphthalene (4.33 g, 0.025 mol) was added to the pot. The mixture was stirred for 2–3 h at 50–55 °C. The nitrogen flow was then stopped, but the solution was kept stirring overnight at room temperature. The reaction was quenched with saturated aqueous NH_4Cl. The crude product (38.9 g, 55.5% based on 1-nitronaphthalene) was subjected to column chromatography (Merck silica gel 60), with hexane as eluent. Yellow needles, mp 285–6 °C (lit.[3] 285 °C); mass spectrum (EI, 70 eV) *m/z* 280 (M^+, base), 251, 140, 126, 100; IR (KBr disk) 880, 1220, 1346, 1390, 1508, 3440 (br) cm^{-1} (cf. ref 7i); UV (λ_{max} in MeOH) 242.8, 291.0, 391.8, 414.4 nm (cf. ref 7i); NMR (in $CDCl_3$) H1 9.45, H4 8.01, C1 124.9, C6 127.4 ppm; Anal. Calcd for $C_{20}H_{12}N_2$: C, 85.69; H, 4.32; N, 9.99. Found: C, 85.81; H, 4.37; N, 9.83.

Dibenzo[*a,j*]phenazine. 1-Aminonaphthalene (1.43 g, 0.01 mol), 2-aminonaphthalene (1.43 g, 0.01 mol) and *t*-BuOK (4.6 g) were added to dried toluene (100 mL). Pure oxygen gas was bubbled through the solution for 4 h at room temperature. The reaction mixture was neutralized with 2 N H_2SO_4, and the solvent was removed with steam. The isolated product (2.17 g) was purified with hexane on a column of silica gel. The major fraction was solidified and recrystallized from benzene–*n*-hexane. Yellow needles (1.57 g, 56.1%), mp 245–6 °C (lit.[7f] 243 °C); mass spectrum (EI, 70 eV) *m/z* 280 (M^+, base), 251, 140, 126; IR (KBr disk) 834, 878, 1250, 1370, 3450 (br) cm^{-1}; UV (λ_{max} in MeOH) 291.2, 265.4, 397.8, 413.6 nm; NMR (in $CDCl_3$) H1 9.60, H4 7.95, C1 125.1, C6 126.9 ppm. Anal. Calcd for

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$C_{20}H_{12}N_2$: C, 85.69; H, 4.32; N, 9.99. Found: C, 85.76; H, 4.47; N, 9.77. The minor fraction gave yellow needles (0.21 g, 7.5%), which were identified to be the [*a*,*h*] isomer.

NMR Measurements. All proton, selective proton decoupling, carbon-13, and COSY spectra were recorded on a Bruker AC-250. The NOE and relaxation times were measured by a JEOL 400 at ambient temperatures.

MO Calculations. The MNDO-PM3 method was used with MOPAC 7[18] on an IBM PS/55 personal computer.

Supporting Information Available: CH COSY spectra of the [*a*,*h*] and [*a*,*c*] isomers and MNDO PM3 data on electron population, bond order, and bond distance of the four isomers of dibenzophenazines (4 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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