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Static and Dynamic Stereochemistry of *N*-(9-Triptycyl)acetanilide

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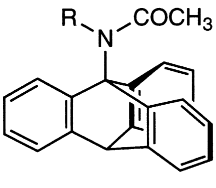
X-ray crystallography and dynamic NMR spectroscopy of the title compound revealed (1) pyramidality of the N atom, (2) strong preference for *Z*-configuration of the amide bond, and (3) very high (67.4 kJ mol^{-1}) and very low ($\ll$ 35 kJ mol^{-1}) energy barriers to "Ac-passing" and "Ph-passing", respectively.

We recently reported molecular structures and stereodynamics of *N*-alkyl-*N*-(9-triptycyl)acetamides **1**–**3**.[1] The most significant feature of the molecular structures of these compounds is that the nitrogen atom of the amide moiety is not planar but is pyramidalized to some extent. The pyramidalization is ascribed to the steric repulsion between the *N*-alkyl group and the triptycene (Tp) skeleton. Among other intriguing features in these compounds is the stereodynamics of the amide bond and the Tp–N bond in solution. It is of interest how these features appear in *N*-aryl derivatives of *N*-(9-triptycyl)acetamide. We report here the X-ray crystallographic and dynamic NMR spectroscopic studies of *N*-(9-triptycyl)acetanilide (**4**) (Chart 1).

Figure 1 shows the molecular structure of compound **4**, which was synthesized in 14% yield by acetylation of *N*-(9-triptycyl)aniline.[2] The amide moiety adopts the *Z*-configuration, similarly to what was observed in *N*-methylacetanilide (**5**).[3] The acetyl group almost bisects the notch made by the two benzene rings of the Tp skeleton. The nitrogen atom is somewhat pyramidalized and the sum of the bond angles around the nitrogen is 355.7°, which is larger than those found for **1** (352°) and **3** (350°). The phenyl group is tilted over one of the Tp benzene rings: the C7–N–C3–C4 angle is 30.3° and the C3–N–C7–C8 angle is 52.6°. This is compared with the fact that the Ph plane is almost perpendicular to the amide plane in **5** (Scheme 1). Replacement of the methyl group in **5** with the Tp group may cause the nitrogen pyramidalization and the twisting of the Ph-N bond from the perpendicular conformation due to the severe steric interaction between the Ph and Tp moieties in **4.**



1: $R = CH_3$
2: $R = C_2H_5$
3: $R = CH_2C_6H_5$
4: $R = C_6H_5$

Chart 1.

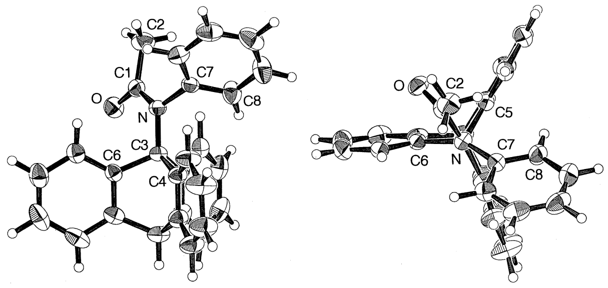
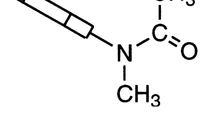


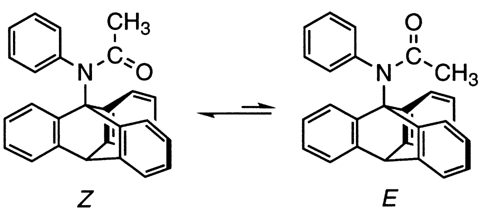
Fig. 1. Perspective drawings of the molecular structure of compound **4**.

In the ^{1}H NMR spectrum of **4** in $CDCl_3$ at 23 °C, the acetyl methyl group appears as a single broad peak at δ 2.21 with a half-height width of ca. 5 Hz. The signal sharpened upon elevation of the temperature, and also sharpened without splitting upon the decrease of temperature. This phenomenon is interpreted in terms of the $Z \rightleftarrows E$ equilibration of the amide bond as follows (see Scheme 2). At temperatures lower than −20 °C, the $Z \rightleftarrows E$ interconversion is slow on the NMR time scale but the equilibrium is overwhelmingly one-sided, the minor isomer being undetectable (< ca. 1%). The chemical shift of the methyl signal at δ 2.26 at −40 °C suggests the predominance of the *Z* isomer, judging from the data for compounds **1**–**3**: the *E* isomer will give the signal around δ 1.7 due to the ring current effect of the near-by benzene rings of the Tp moiety.[1] Upon elevation of the temperature from −40 °C, the population of the less stable *E* isomer gradually increases and the isomer interconversion becomes faster, resulting in a broadened single peak around room temperature. At 50 °C, a sharp signal is observed at δ 2.15 due to the fast isomer interconversion on the NMR time scale. Gradual upfield shift of the signal upon elevating the temperature may also be the reflection of the increasing population of the *E* isomer.

The larger population of the *Z*-isomer in **4** than in the *N*-alkyl compounds **1**–**3** (86, 42, and 78%, respectively, in $CDCl_3$ at 250 K[1]) is in conformity with the strong preference for the *Z*-isomer found in *N*-methylacetanilide.[3]



Scheme 1.



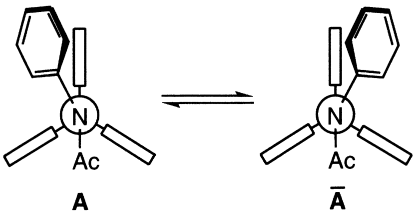
Scheme 2.

The aromatic region of the ^{1}H NMR spectrum of **4** at 23 °C reveals that one of the three benzene rings of the Tp moiety appears as magnetically different from the other two, and that the peri-proton on the unique benzene ring gives its signal at a very high field of δ 5.48.

These findings are most reasonably explained as follows. The molecule of **4** is assumed to adopt a similar conformation in solution as in the crystal, schematically shown as **A** and **$\bar{\text{A}}$** in Scheme 3. The passing of the phenyl group over a benzene ring (hereafter referred to as "Ph-passing") interconverts the enantiomeric forms **A** and **$\bar{\text{A}}$**, and it takes place quickly on the NMR timescale. Meanwhile the passing of the acetyl group over a benzene ring ("Ac-passing") is slow on the NMR timescale. In these situations, the two benzene rings flanking the acetyl group will be equivalent but the third benzene ring will be unique, and the peri-proton on this ring will appear at a high field due to the ring-current effect of the phenyl group.

Even at -100 °C in CD_2Cl_2, the two benzene rings flanking the acetyl group remain equivalent without any significant signal broadening, indicating that "Ph-passing" is still fast at this temperature. The free-energy barrier is estimated to be far lower than 35 kJ mol^{-1}. The two ortho protons as well as the two meta protons of the phenyl group are also equivalent at -100 °C. This will be understood by assuming that "Ph-passing" is always accompanied by the exchange of the two edges of the Ph group, which will be easily seen from Scheme 3. In *N*-(9-triptycyl)aniline, "Ph-passing" accompanied by the edge exchange has the free-energy barrier of ca. 40 kJ mol^{-1}.[2] Destabilization of the ground state would be the main reason for the lower barrier in **4**.

Upon elevation of the temperature above 23 °C, the aromatic Tp proton signals broaden and then coalesce so as to equalize the three benzene rings by "Ac-passing". Saturation transfer experiments in the range of 0–30 °C in $CDCl_3$ gave the following kinetic parameters for "Ac-passing": $\Delta H^{\ddagger} = 64.3 \pm 5.4$ kJ mol^{-1}, $\Delta S^{\ddagger} = -10 \pm 20$ J mol^{-1} K^{-1}, $\Delta G^{\ddagger}$ (300 K) = 67.4 kJ mol^{-1}. The free-energy barrier to "Ac-passing" is far higher than those found in **1**–**3**, which are ca. 40 kJ mol^{-1}.[1] This may be ascribed to the "buttressing effect" of the phenyl group at the transition state for "Ac-passing". Thus, contrary to the primary alkyl groups in **1**–**3**, the bulky phenyl group in **4** sterically interacts strongly with the Tp moiety and buttresses the Ac group so as to prevent the widening of the Ac–N–Tp bond angle at the transition state.



Scheme 3.

Experimental

General. Melting points are not corrected. ^{1}H and ^{13}C NMR spectra were obtained on a Bruker ARX-300 spectrometer operating at 300.1 MHz for ^{1}H and 75.4 MHz for ^{13}C, respectively. Chemical shifts were referenced with internal tetramethylsilane ($\delta_H = 0$) or $CDCl_3$ ($\delta_C = 77.0$). Letters p, s, t, and q given with the ^{13}C chemical shifts denote primary, secondary, tertiary, and quaternary, respectively. In variable-temperature NMR experiments, temperatures were calibrated using a methanol or an ethylene glycol sample and are reliable to ±1 °C.

***N*-(9-triptycyl)acetanilide (4).** To a solution of 304 mg (0.88 mmol) of *N*-(9-triptycyl)aniline in 20 mL of dichloromethane was added 0.63 mL (8.8 mmol) of acetyl chloride, and the mixture was heated under reflux for 60 h. The mixture was washed successively with aq $NaHCO_3$, water, and brine and dried over $MgSO_4$. After removal of the solvent, the residue was chromatographed on alumina with dichloromethane–hexane (1 : 1) as the eluent to afford 46 mg (14%) of **1**, mp 273–274 °C. Found: C, 86.59; H, 5.57; N, 3.63%. Calcd for $C_{28}H_{21}NO$: C, 86.79; H, 5.46; N, 3.61%. ^{1}H NMR ($CDCl_3$, 23 °C) δ 2.21 (3H, br s), 5.31 (1H, s), 5.48 (1H, br d, $J \sim 8$ Hz), 6.37 (1H, br t, $J \sim 8$ Hz), 6.71 (1H, br t, $J \sim 8$ Hz), 6.95–7.28 (5H, m), 7.32–7.60 (7H, m), 7.70 (2H, m). ^{13}C NMR ($CDCl_3$, -20 °C) δ 26.05 (1C, p), 54.08 (1C, t), 74.50 (1C, q), 123.17 (1C, t), 123.41 (1C, t), 123.54 (2C, t), 123.66 (2C, t), 123.71 (1C, t), 124.18 (1C, t), 124.34 (2C, t), 125.45 (2C, t), 129.07 (1C, t), 129.81 (2C, t), 130.59 (2C, t), 141.90 (2C, q), 142.92 (2C, q), 143.07 (1C, q), 143.18 (1C, q), 147.16 (1C, q), 171.13 (1C, q).

Saturation Transfer Experiments.[4] The signal at δ 7.44 due to the two equivalent peri-protons of **4** was irradiated and the change in the intensity of the signal at δ 5.48 due to the unique peri-proton was observed. Nonlinear least-squares analysis of the data afforded the rate constants.

X-ray Crystallography. Crystals of compound **4** were grown from ethyl acetate-hexane. Diffraction data were collected on a Rigaku AFC7R diffractometer and calculations were performed using the SHELXL93 program.[5] The structure was solved by direct methods followed by full-matrix least-squares refinement with all non-hydrogen atoms anisotropic and hydrogen atoms isotropic. The function minimized was $\Sigma w(|F_o| - |F_c|)^2$ where $w = [\sigma^2(F_o)]^{-1}$.

Crystallographic data: $C_{28}H_{21}NO$, Fw = 387.49, monoclinic, $P2_1/a$, $a = 9.038(11)$, $b = 14.200(8)$, $c = 16.086(7)$ Å, $\beta = 100.83(6)°$, $V = 2027.6(29)$ Å^3, $Z = 4$, $D_{calc} = 1.269$ g cm^{-3}, $R = 0.0429$, $R_w = 0.1014$ on F^2, 3192 unique reflections with $|I| > 2\sigma(I)$.

Crystallographic data have been deposited at the CCDC, 12 Union Road, Cambridge, CB2 1EZ, UK and copies can be obtained on request, free of charge, by quoting the publication citation and the deposition number CCDC 167136, and the final atomic parameters and structure factors have been deposited as Document No. 74049 at the Office of the Editor of Bull. Chem. Soc. Jpn.

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