JACS
ARTICLES

# A Threefold "Butterfly Valve" in Command of the Encapsulation's Kinetic Stability. Molecular Baskets at Work

*Bao-Yu Wang, Xiaoguang Bao, Zhiqing Yan, Veselin Maslak, Christopher M. Hadad and Jovica D. Badjić**

*Contribution from the Department of Chemistry, The Ohio State University, 100 W. 18th Avenue, Columbus, OH 43210*

E-mail: *badjic@chemistry.ohio-state.edu*

# Supporting Information

## General Information

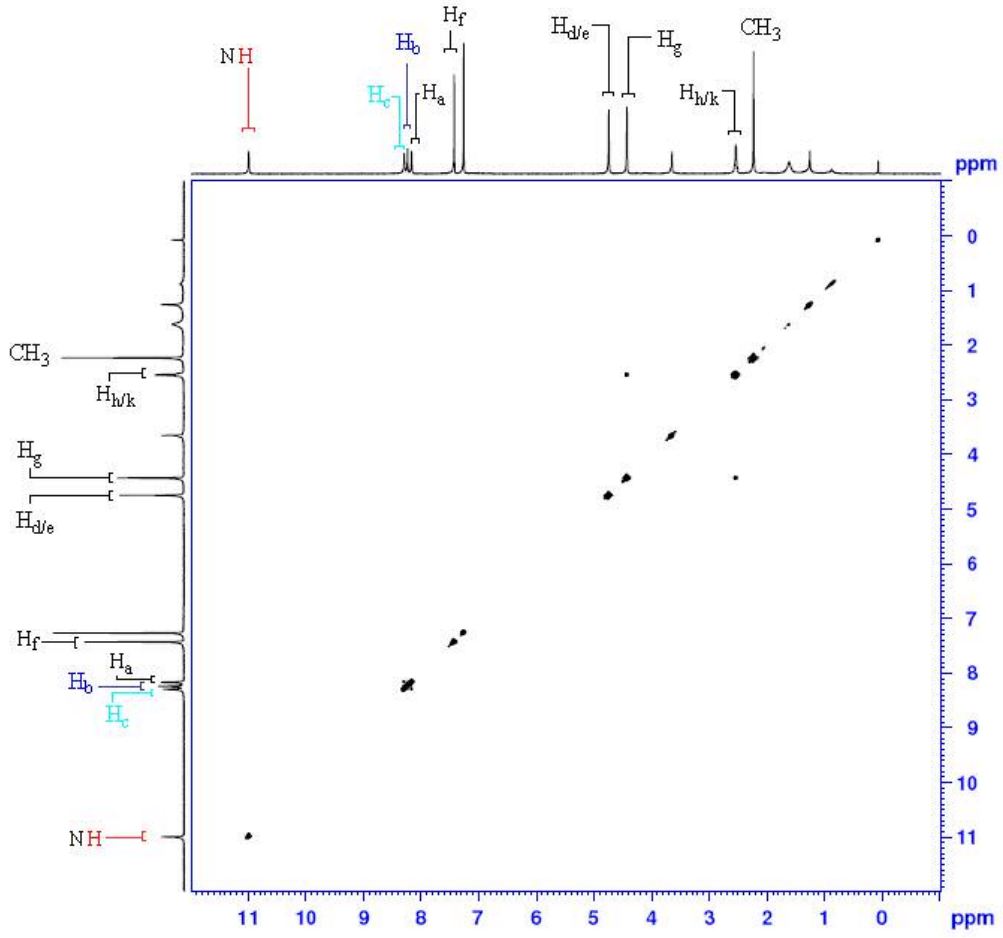
All chemicals were purchased from commercial sources, and used as received unless stated otherwise. All solvents were dried prior to use according to standard literature protocols. Chromatography purifications were performed using silica gel 60 (Sorbent Technologies 40-75μm, 200 x 400 mesh). Thin-layer chromatography (TLC) was performed on silica-gel plate w/UV254 (200μm). Chromatograms were visualized by UV-light and stained using 20% phosphomolybdic acid in ethanol, if required. All NMR samples were prepared in J. Young Valve NMR Tubes purchased from Norell. $^{1}H$ and $^{13}C$ NMR spectra were recorded, at 400 MHz and 100 MHz respectively, on a Bruker DPX400 spectrometer. They were referenced using the solvent residual signal as an internal standard. NMR samples were prepared using $CDCl_3$ and $CD_2Cl_2$ purchased from Cambridge Isotope Laboratories. The chemical shift values are expressed as $\delta$ values, and the couple constants (*J*) are given in Hertz (Hz). The following abbreviations have been used for the signal multiplicities: s, singlet; d, doublet; t, triplet; m, multiplet; and br, broad. Reported temperatures were corrected with a neat methanol standard.[1] HR MALDI-TOF mass spectra were measured on a Bruker Relfex III MALDI-TOF spectrometer on samples made with 2,5-dihydroxybenzoic acid.

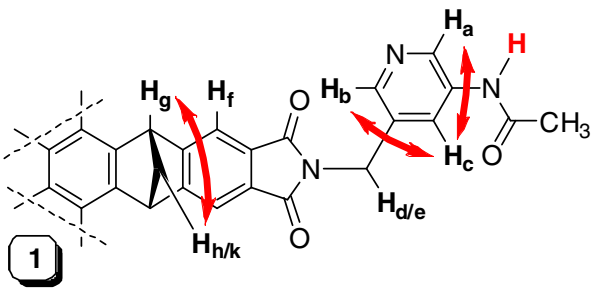
**Synthetic Procedures**

**Molecular basket 1:** A solution (dry DMSO, 5.0 mL) of *tris*-anhydride **3** (8.8 mg, 0.014 mmol) and **4** (7.0 mg, 0.042 mmol) was stirred for 30 min under an atmosphere of nitrogen (room temperature). Subsequently, neat pyridine (0.5 mL) was added portionwise and the temperature was raised to 120 $^{o}$C. The reaction was allowed to complete for 12 h (overnight), after which the solvent was evaporated in *vacuum* and the residue purified by column chromatography ($SiO_2$, $CH_2Cl_2$/$CH_3OH$ = 8:1) to yield desired **1** as a white solid (9.5 mg, 63 %). $^{1}$H NMR (400 MHz, $CDCl_3$, 298 K): $\delta$ = 10.98 (s, 3-NH), 8.29 (t, $J$ = 1.6 Hz, 3H), 8.24 (d, $J$ = 1.6 Hz, 3H), 8.16 (d, $J$ = 2.4 Hz, 3H), 7.43 (s, 6H), 4.74 (s, 6H), 4.23 (s, 6H), 2.54 (q, $J$ = 3.6 Hz, 6H) and 2.23 ppm (s, 9H); $^{13}$C NMR (100 MHz, $CDCl_3$, 298 K): $\delta$ = 169.7, 167.0, 156.7, 145.1, 142.3, 137.5, 135.2, 134.9, 133.3, 130.1, 116.1, 66.1, 49.0, 38.3 and 23.7 ppm; HR MALDI-TOF *m/z* calcd for $C_{63}H_{46}N_9O_9$: 1072.3418 $[M+H]^+$, found: 1072.2285.

**Model compound 2:** A solution (dry DMSO, 2.0 mL) of phthalic anhydride (3.0 mg, 0.02 mmol) and **4** (3.3 mg, 0.02 mmol) was stirred for 30 min under an atmosphere of nitrogen (room temperature). Subsequently, neat pyridine (0.2 mL) was added portionwise and the temperature was raised to 120 $^{o}$C. The reaction was allowed to complete for 12 h (overnight), after which the solvent was evaporated in *vacuum* and the residue purified by column chromatography ($SiO_2$, $CH_2Cl_2$/$CH_3OH$ = 8:1) to yield a white solid (4.1 mg, 70 %). $^{1}$H NMR (400 MHz, $CDCl_3$, 298 K): $\delta$ = 8.62 (d, $J$ = 2.4 Hz, 1H), 8.44 (d, $J$ = 1.2 Hz, 1H), 8.08 (br, 1H), 7.87 (m, 2H), 7.73 (m, 2H), 7.4 (br, NH), 4.88 (s, 2H) and 2.19 ppm (s, 3H); $^{13}$C NMR (63 MHz, $CDCl_3$, 298 K): $\delta$ = 168.5, 167.8, 147.5, 145.2, 138.3, 134.2, 131.9, 127.2, 123.5, 123.2, 38.5 and 23.6 ppm; HRMS (EI): *m/z* calcd for $C_{16}H_{13}N_3O_3Na$: 318.0855 $[M + Na]^+$, found: 318.0836.

***Figure S1***. $^{1}$H-$^{1}$H COSY NMR spectrum (400 MHz) of 4.66 mM of molecular basket **1** in $CDCl_3$ at 300K**.**



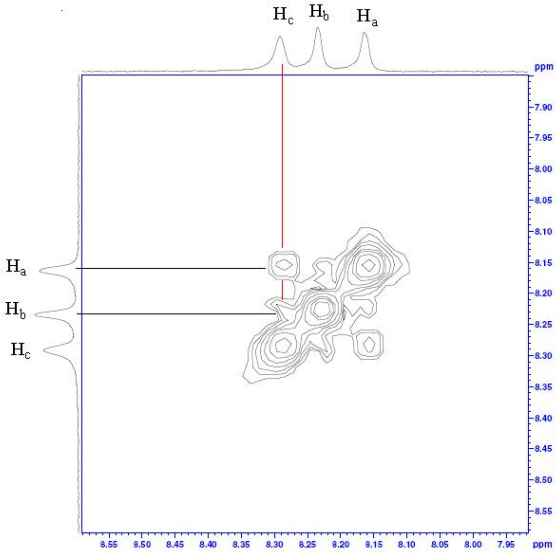



***Figure S2***. $^{1}$H-$^{1}$H ROESY NMR spectrum (400 MHz) of molecular basket **1** in $CDCl_3$ (1.86 mM) at 300 K**.**

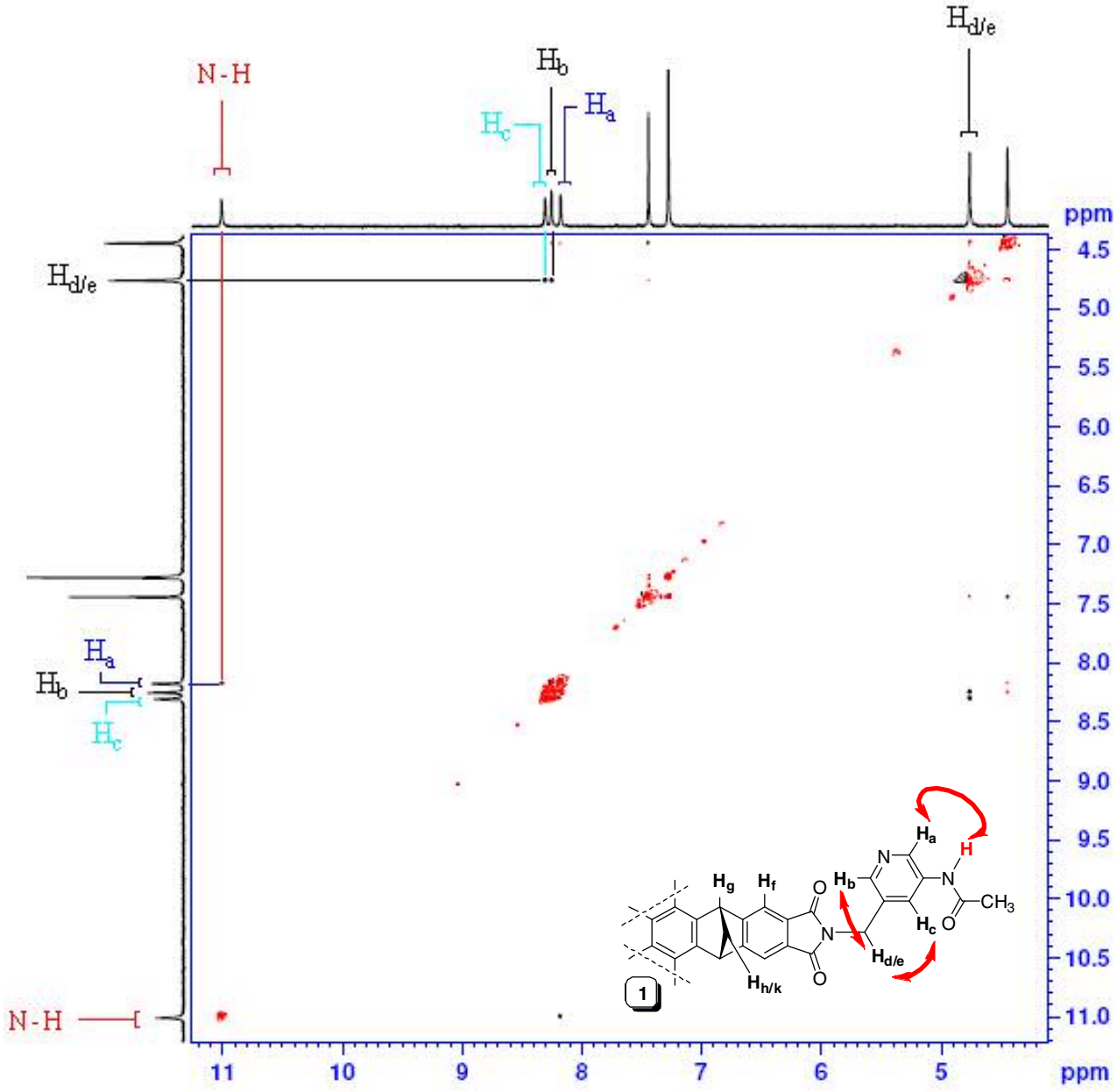


***Figure S3***. $^{1}$H-$^{1}$H NOESY NMR spectrum (400 MHz) of model compound **2** in $CDCl_3$ (12.7 mM) at 300K.

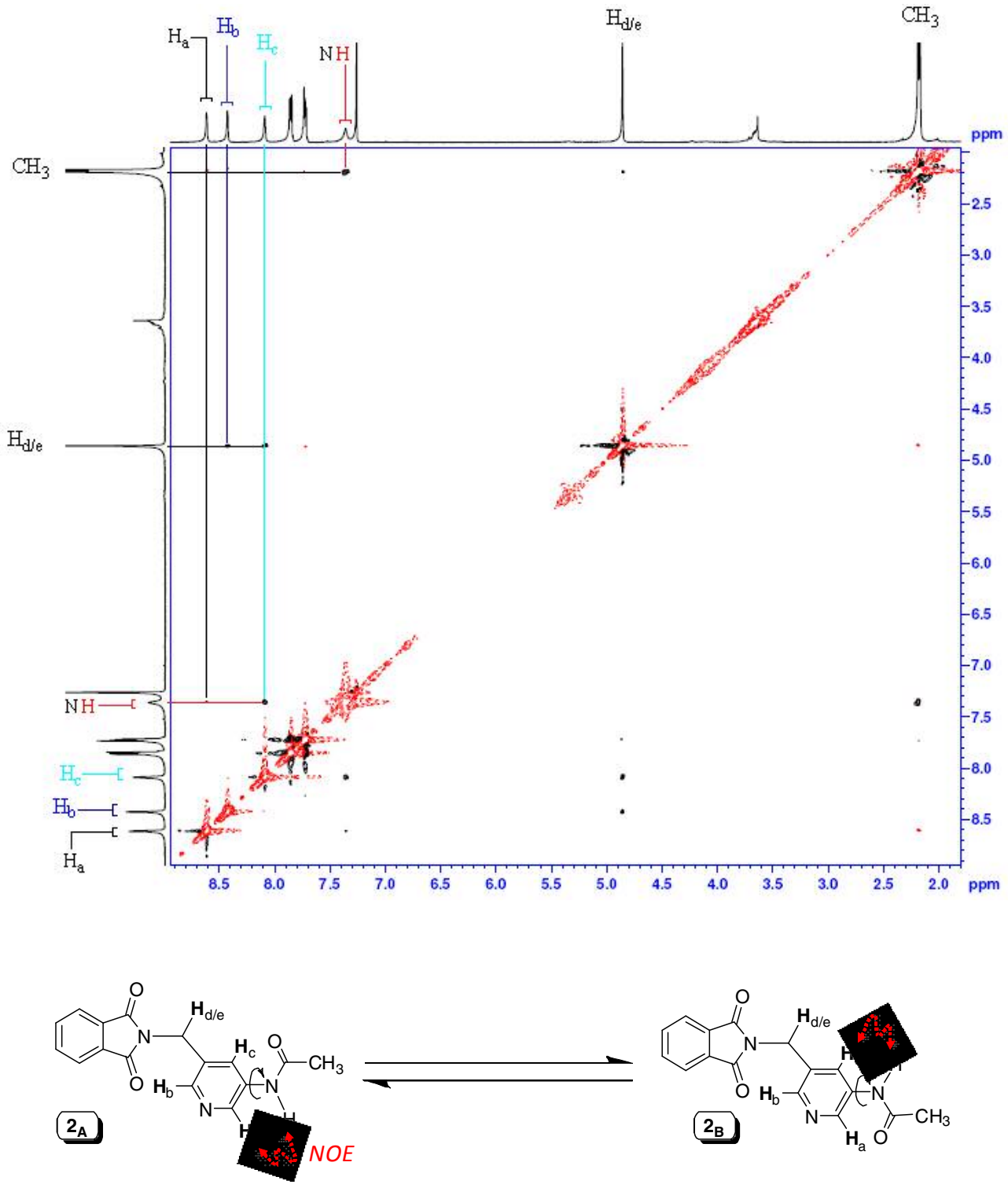
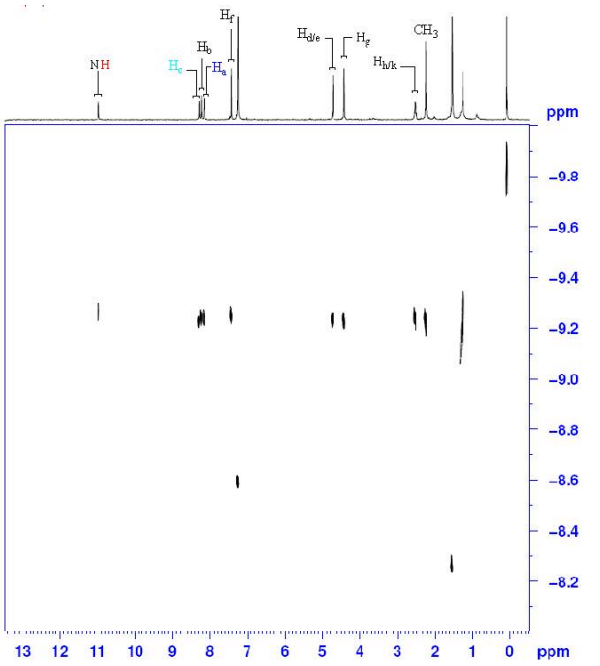


***Figure S4***. (Top) 2D NMR DOSY spectrum (500 MHz) of **1** in $CDCl_3$ (0.7 mM) at 298 ± 1 K; (Bottom) 2D NMR DOSY spectrum (500 MHz) of **1** in $CDCl_3$ (13.0 mM) at 298 ± 1 K.



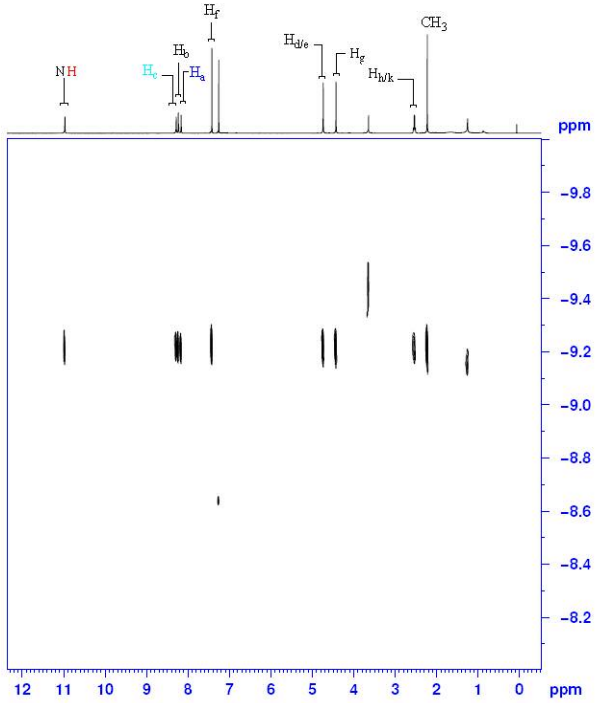



***Figure S5***. High-Resolution MALDI-TOF mass spectrum of **1**, showing a signal at *m/z* 1072.2285 amu corresponding to the [M+H] ion**.** Also, note the presence of $[M+Na]^+$ and $M+K]^+$ ions at 1094 and 1110 amu, respectively.

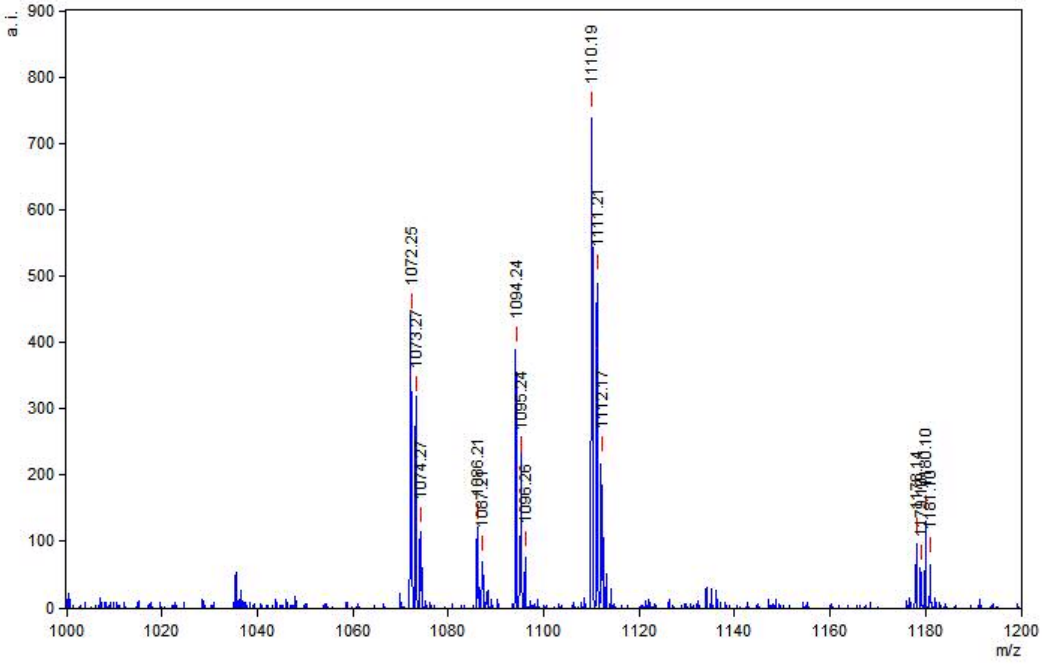


***Figure S6***. A selected region of FT-IR spectra of **1** (from 3600 to 3000 $cm^{-1}$) in $CHCl_3$ (3.0, 6.0 and 12.0 mM) at 298K.

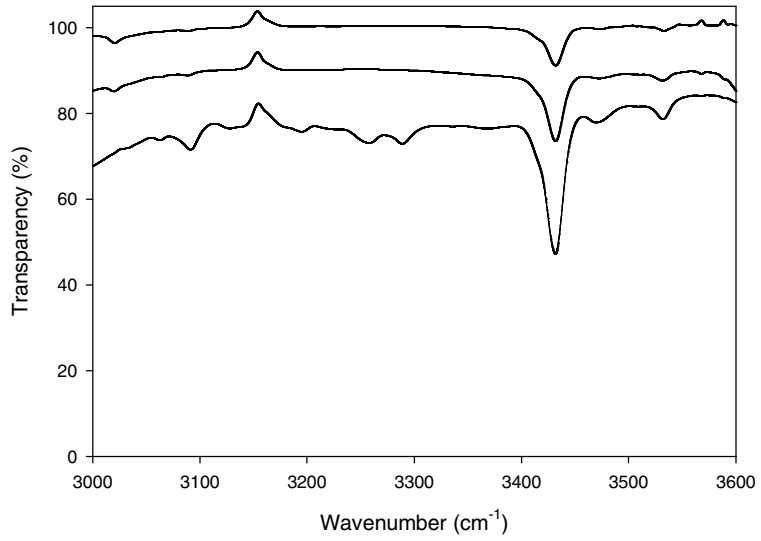



***Figure S7***. A selected region of the FT-IR spectra (from 3600 to 3000 $cm^{-1}$) of **1** in $CDCl_3$ (2.2, 4.4, 8.7, and 17.8 mM) at 298K.

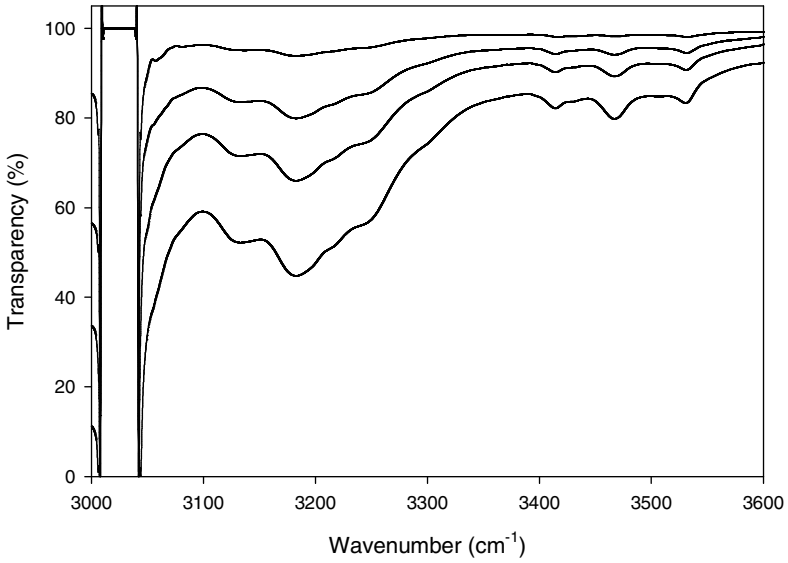


***Figure S8***. Variable temperature (VT) $^{1}$H NMR spectra (400 MHz) of **1** in $CD_2Cl_2$ (2.53 mM).

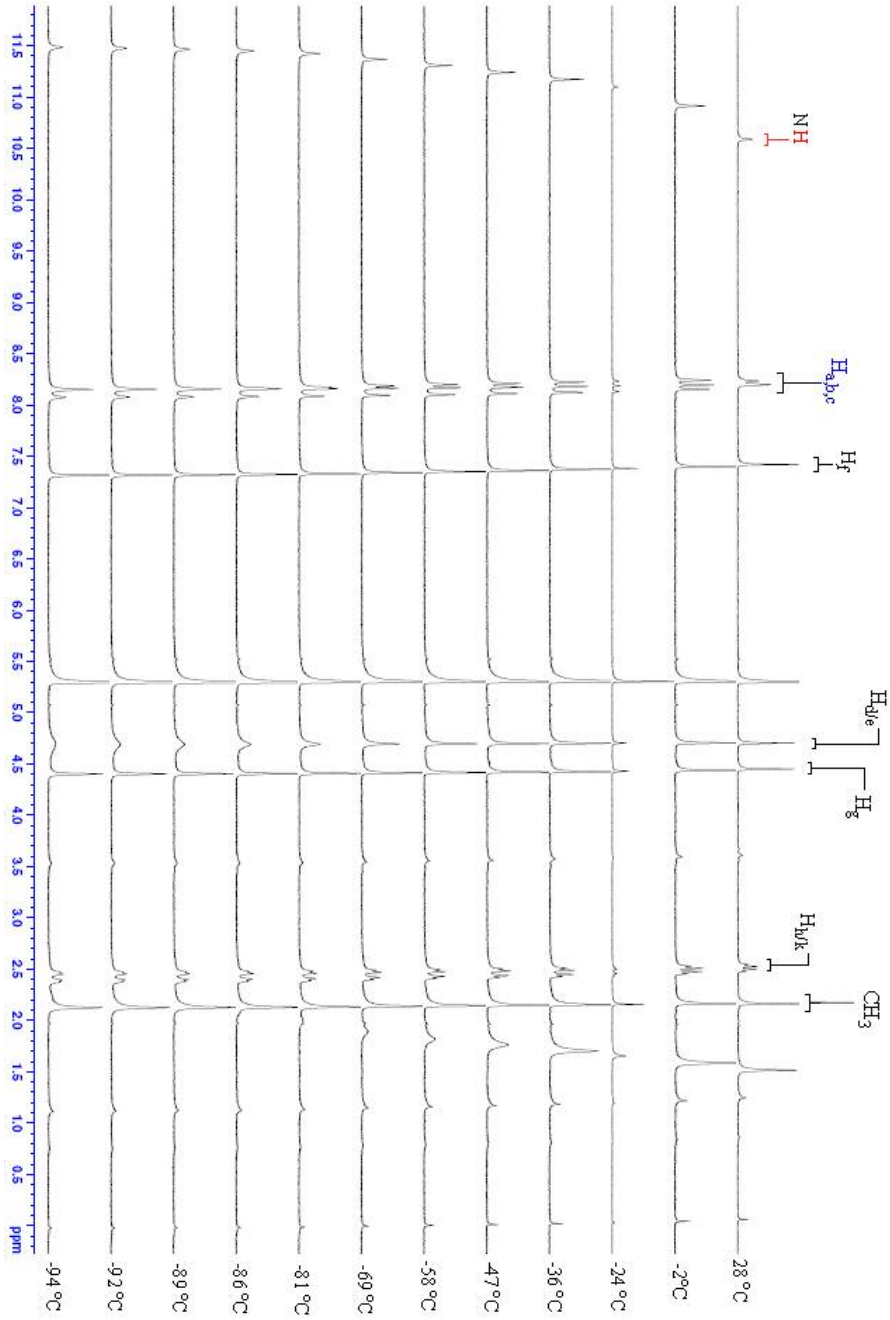


***Figure S9***. Variable temperature (VT) $^{1}$H NMR spectra (400 MHz) of **1** in $CDCl_3$ (1.17 mM).

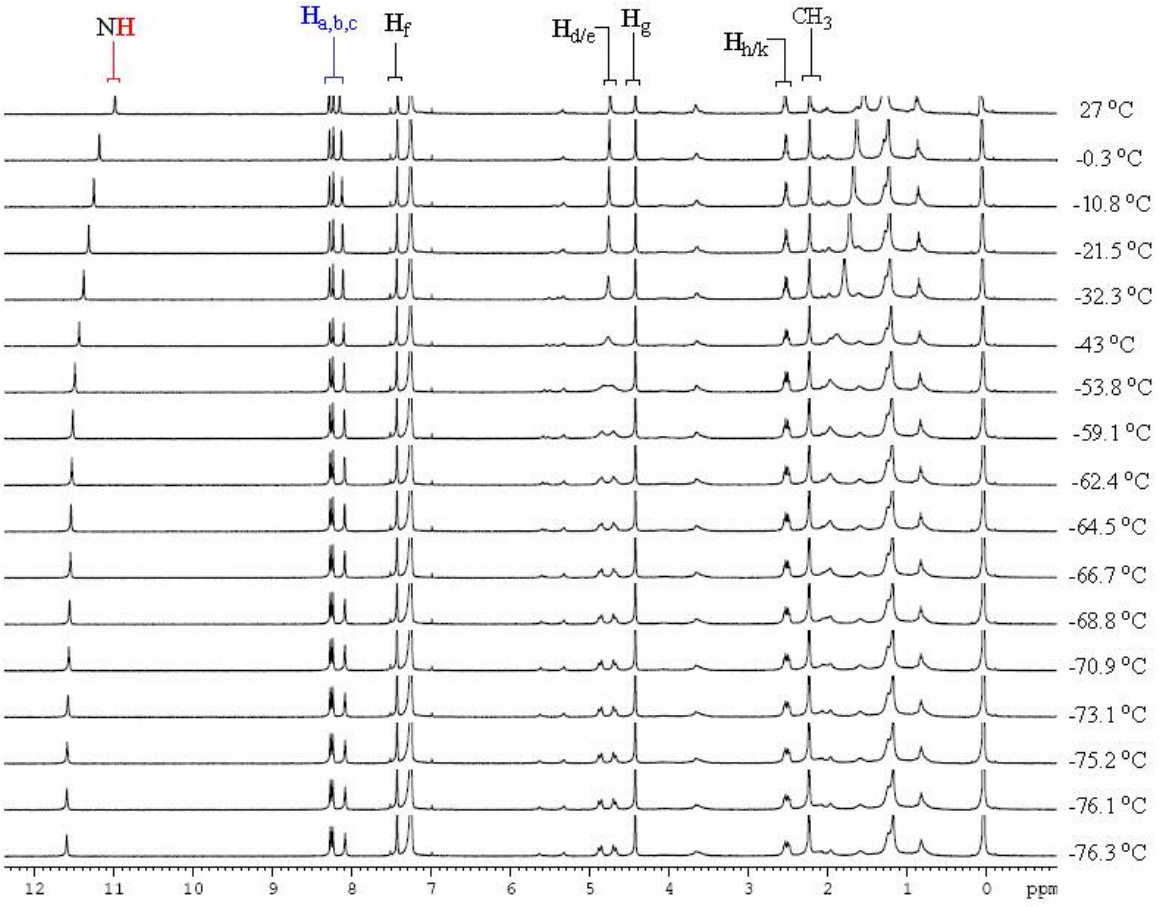


***Figure S10***. Variable temperature (VT) $^1$H NMR spectra (400 MHz) of **1** in $CD_2Cl_2$ (2.4 mM), containing 1.5 molar equivalents of $CCl_4$ (3.7 mM).

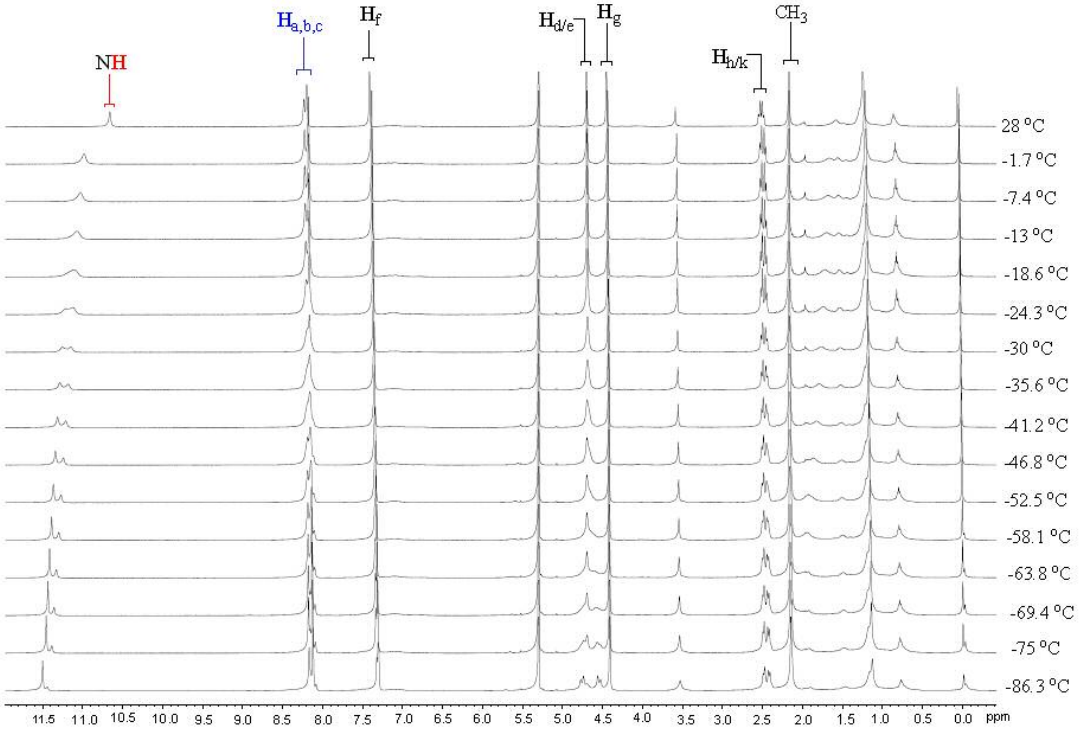



***Figure S11***. Variable temperature (VT) $^1$H NMR spectra (400 MHz) of **1** in $CD_2Cl_2$ (2.98 mM) containing 50.0 molar equivalents of $CCl_4$ (149.0 mM).

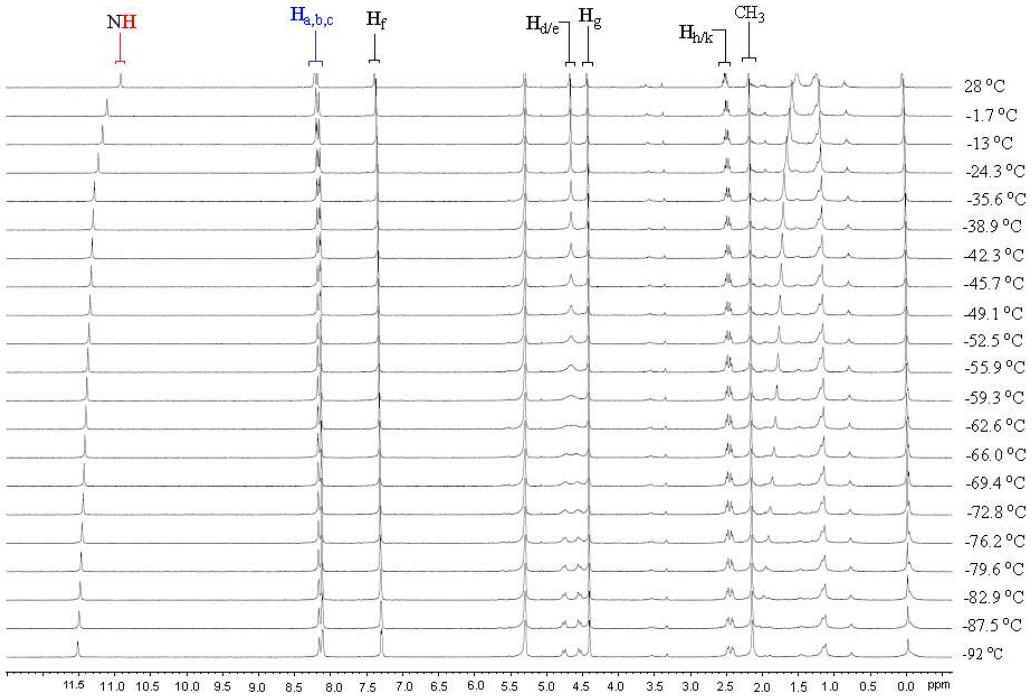
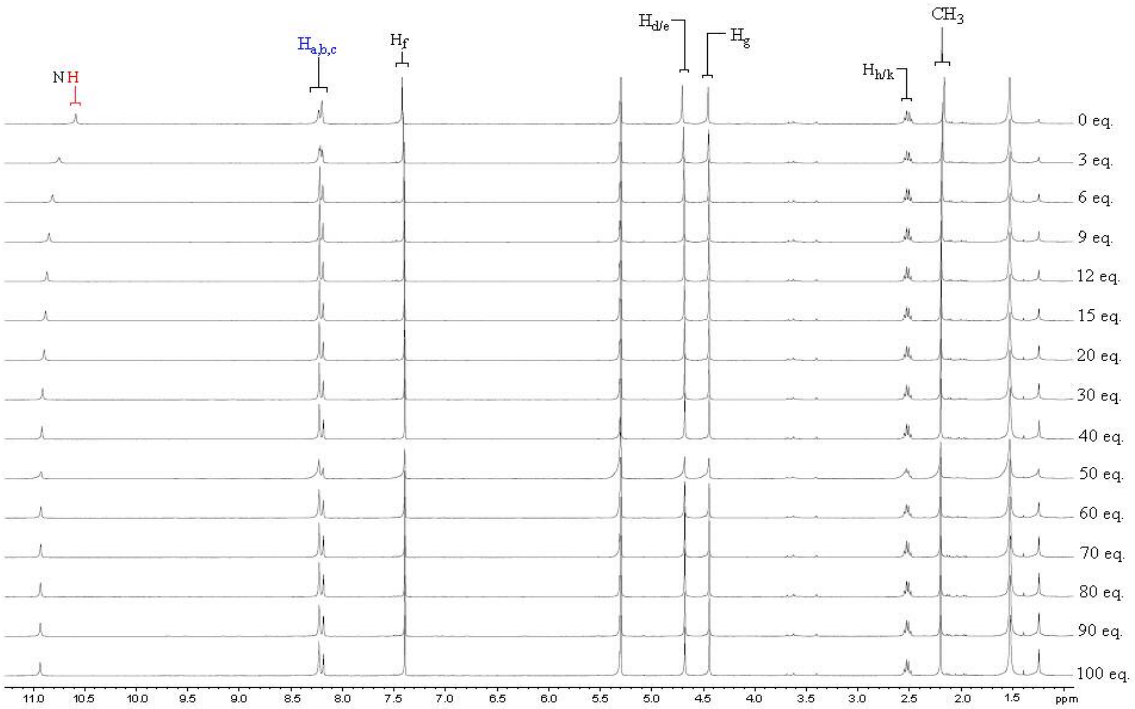


***Figure S12***. $^1$H-NMR spectra (400 MHz) of **1** in $CD_2Cl_2$, (2.98 mM, 298K), obtained after incremental additions of neat $CCl_4$.




The nonlinear curve fitting (SigmaPlot 9.0) of $^1$H NMR chemical shifts of the N–**H** resonance (above) in **1** to a 1:1 equilibrium model (see the main text ref. 17) afforded the association (binding) constant $K_a$.

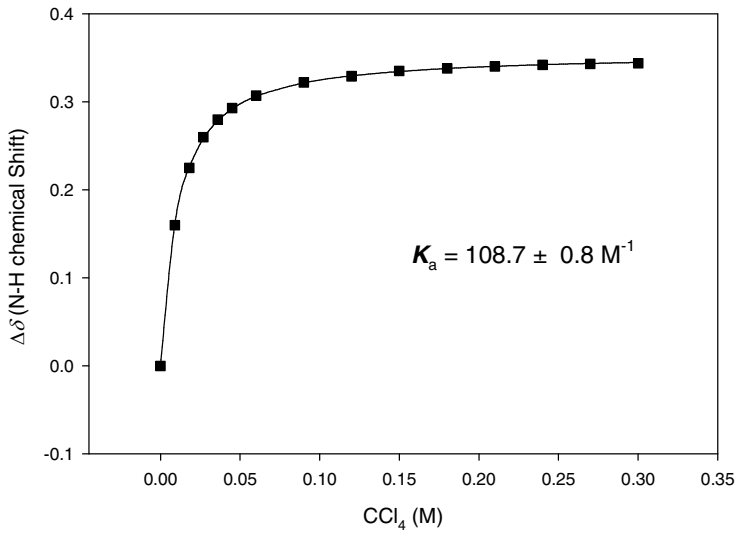


***Figure S13***. $^{1}$H-NMR spectra (400 MHz) of **1** in $CD_2Cl_2$ (2.56 mM, 298 K) obtained after incremental additions of neat $CDCl_3$.

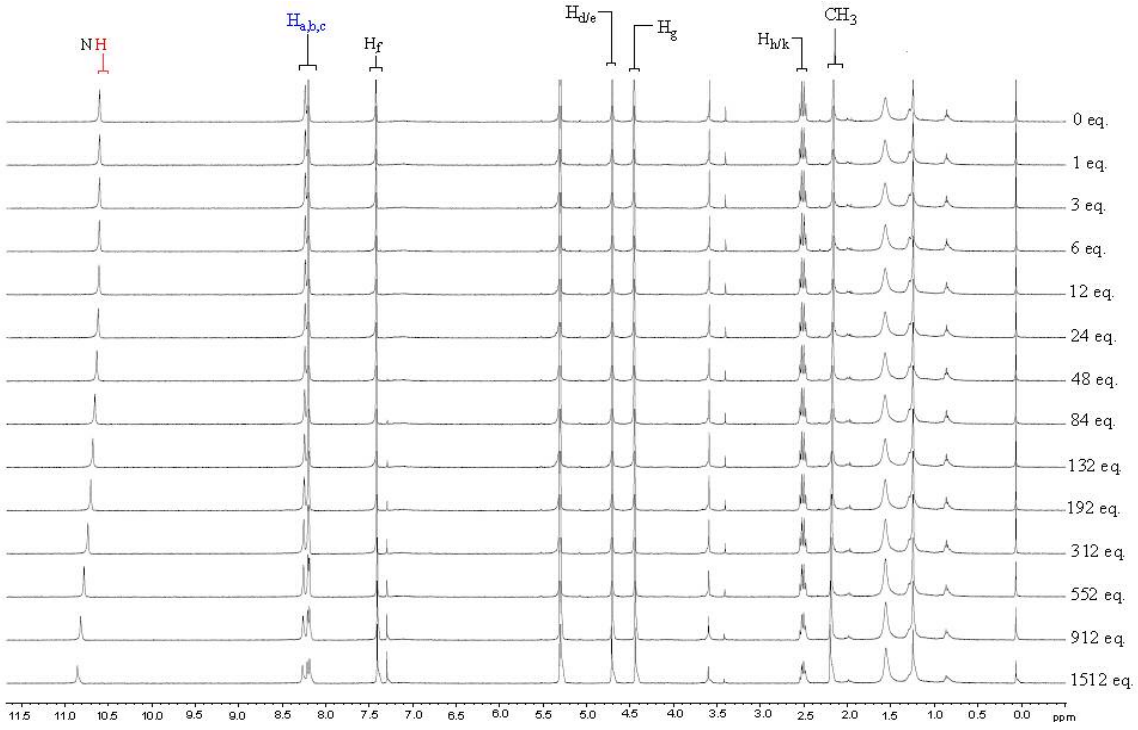
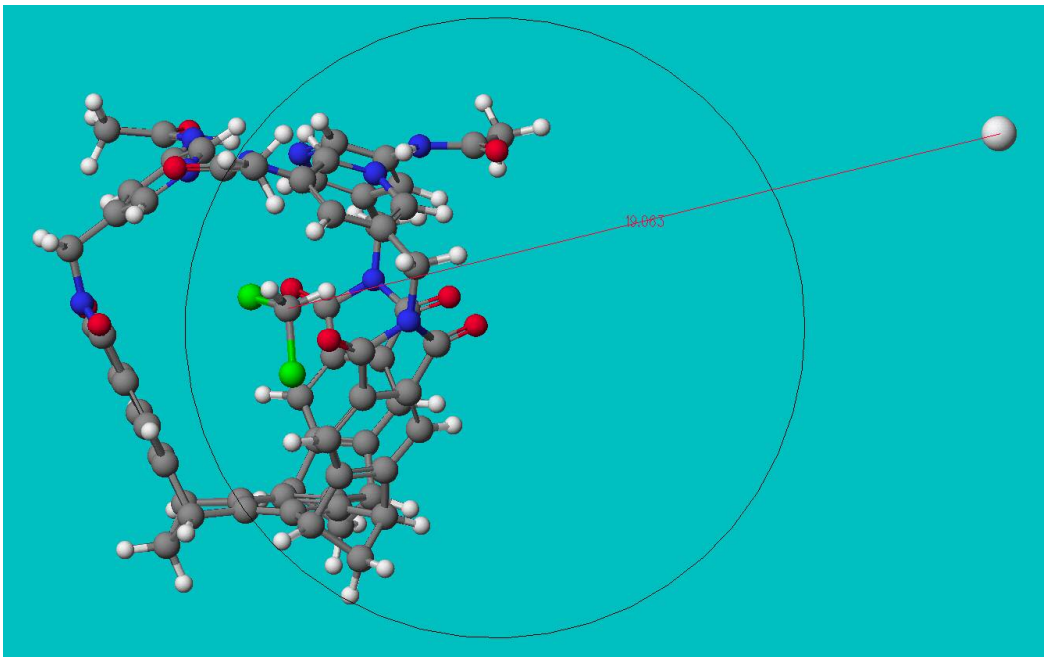


***Figure S14***. The reaction coordinate, χ, for the egress of $CH_2Cl_2$ from **1** (top). Computed energy profiles (PM3, CAChe), for the decomplexation of $CH_2Cl_2$, $CHCl_3$ and $CCl_4$ from **1**, are shown at the bottom. (see ref. 6 in the text)



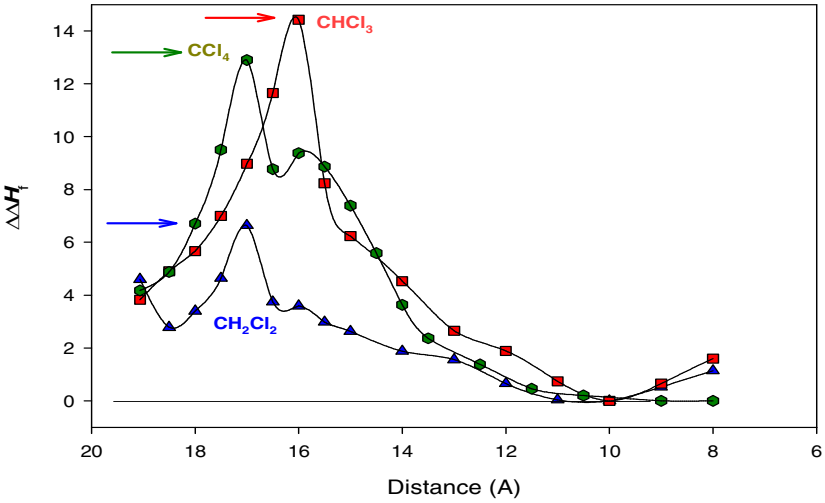
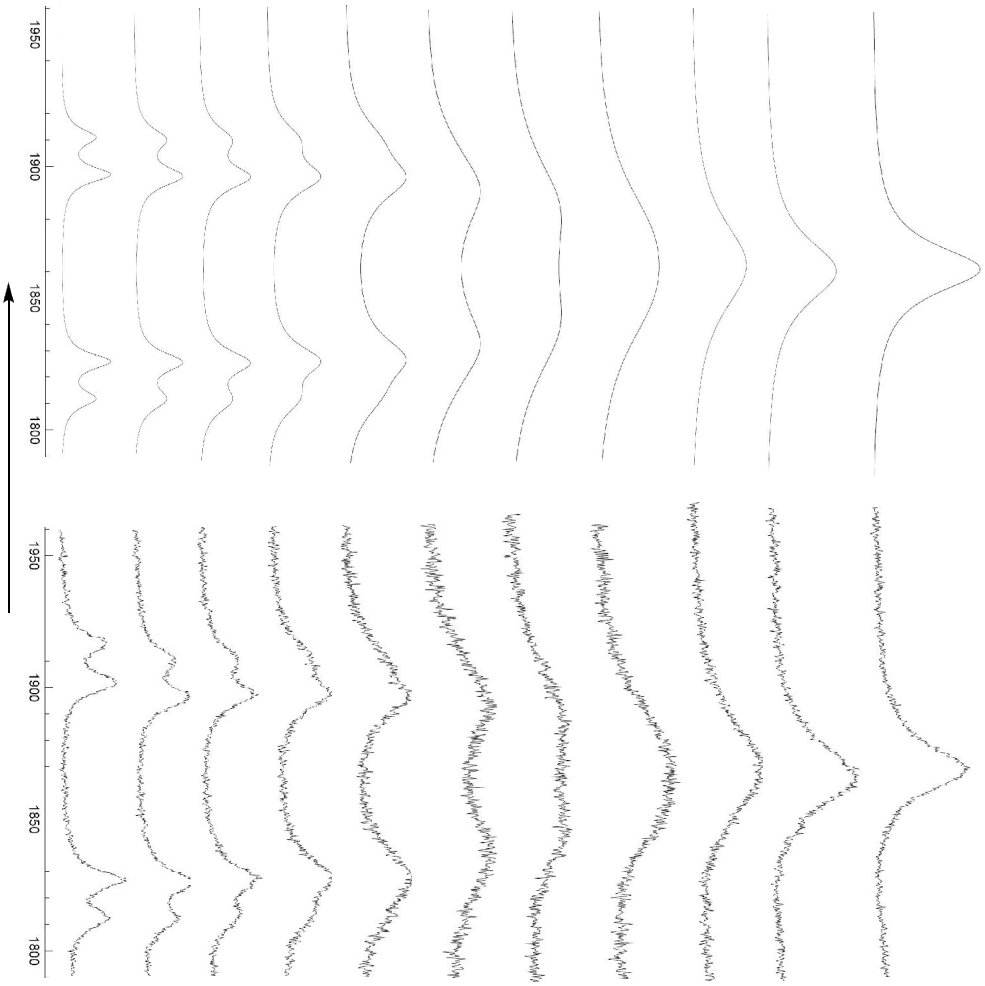


***Figure S15***. Simulated and experimental (WINDNMR-Pro) resonances for the $\mathbf{H}_{d/e}$ protons in **1** ($CD_2Cl_2$, 2.98 mM), containing 50.0 molar equivalents of $CCl_4$ (149 mM). Apparent first-order rate constants $\boldsymbol{k}_1/\boldsymbol{k}_{-1}$ for the $\mathbf{1}_A/\mathbf{1}_B$ interconversion at the examined temperatures.



ERROR: invalidaccess
OFFENDING COMMAND: --filter--

STACK:

/LZWDecode
-filestream-
[40 0 0 -141 0 141 ]
true
141
40
-savelevel-
[1 0 0 -1 0 6600 ]