Supplementary Information

for

Comparison of the acid-base properties of purine derivatives in aqueous solution. Determination of intrinsic proton affinities of various basic sites

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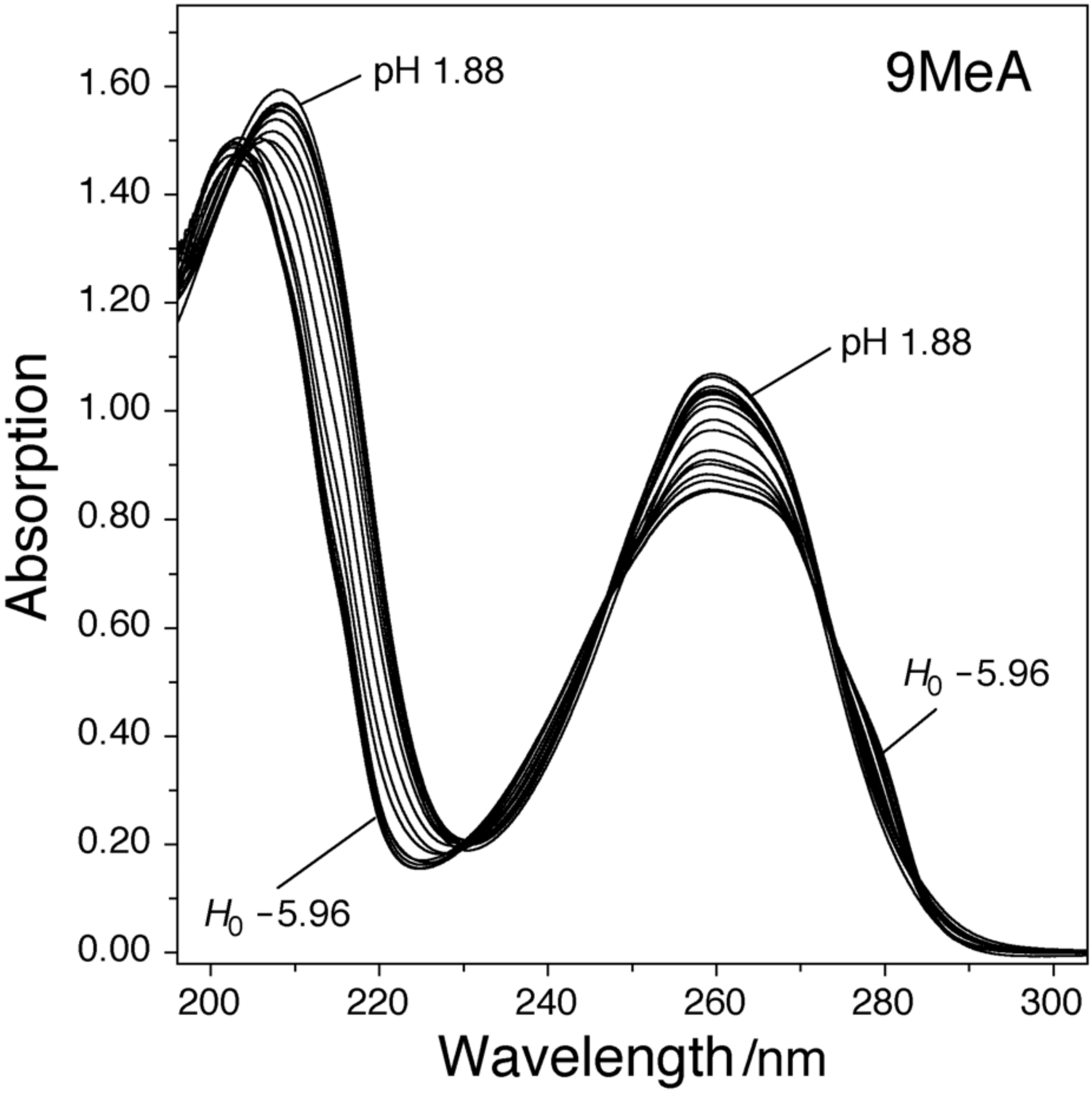

Fig. S1 UV absorption spectra of 9-methyladenine (0.034 mM) measured in 2 cm quartz cells in aqueous solution in dependence on the activity of H^+; i.e., the H_0/pH values (see also Fig. 2 and Sections 2.3 and 2.5) were varied from H_0 –5.96, –5.07, –3.78, –2.47, –1.52, –1.08, –0.86, –0.63, –0.36, –0.10, 0.05, 0.25, 0.46 to 0.79 and pH 1.20, 1.54 to 1.88 (25 °C; I = 0.1 M, $NaClO_4$, except in those solutions where $[HClO_4]$ > 0.1 M). Not all spectral traces of the data points which appear in Fig. 2 are shown.

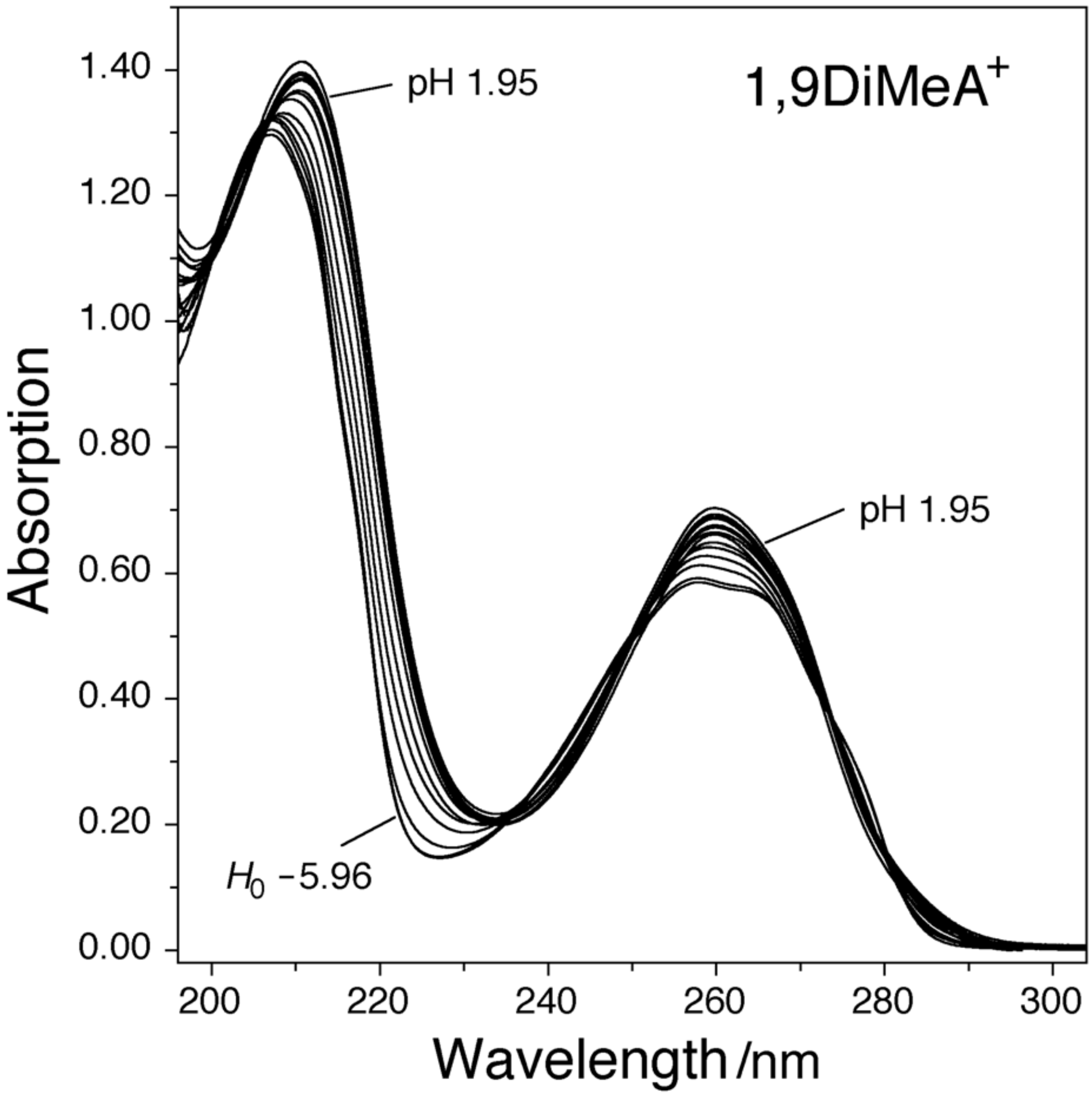

Fig. S2 UV absorption spectra of 1,9-dimethyladenine (0.022 mM) measured in 2 cm quartz cells in aqueous solution in dependence on the activity of H^+; i.e., the H_0/pH values were varied between H_0 –5.96 to 0.79 and pH 1.22 to 1.95 (see legend of Fig. S3); 25 °C; $I = 0.1$ M, $NaClO_4$, except in those solutions where $[HClO_4] > 0.1$ M. Not all spectral traces of the data points which appear in Fig. S3 are shown.

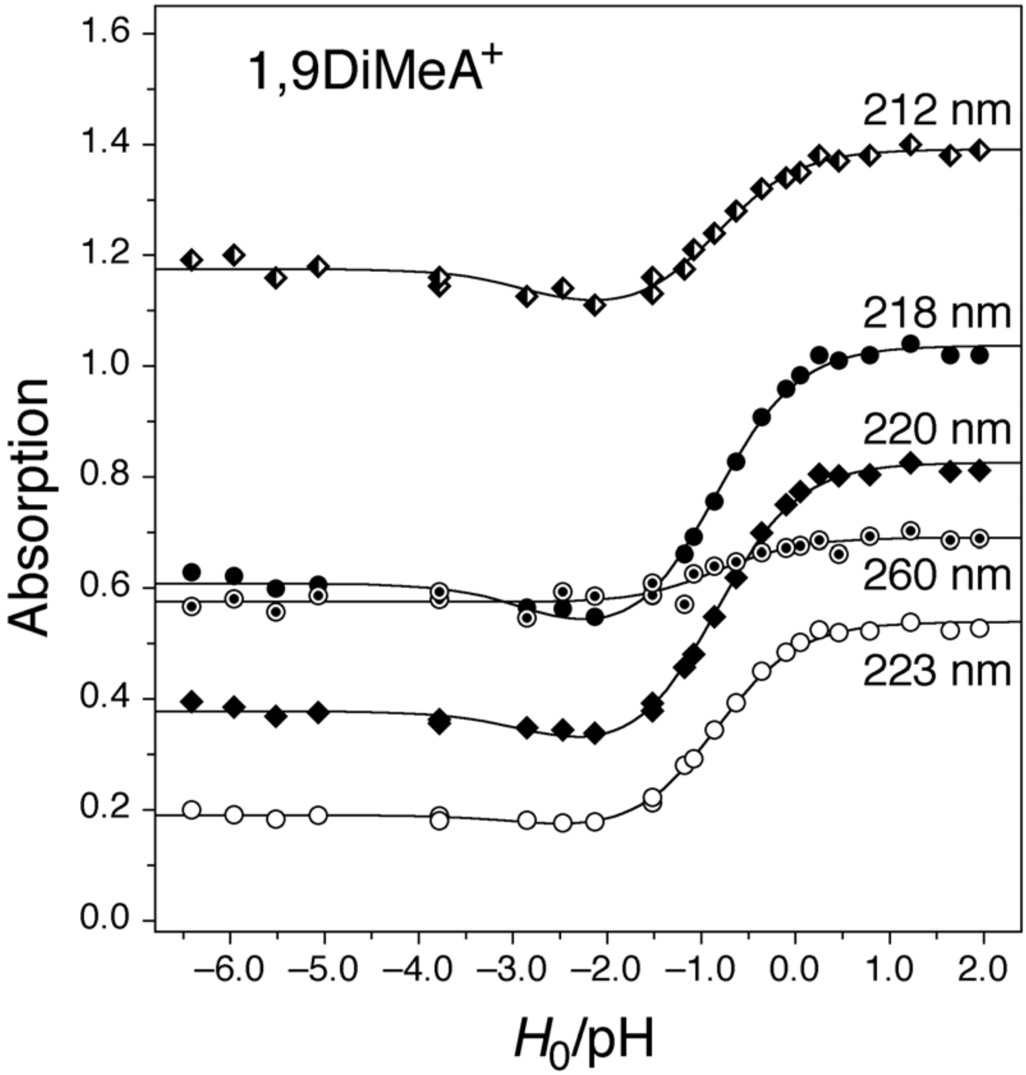

Fig. S3 Evaluation of the dependence of the UV absorption of 1,9-dimethyladenine ($1,9DiMeA^+$) at 212, 218, 220, 223 and 260 nm on the activity of H^+ in aqueous solution (see Fig. S2) by plotting the absorption versus H_0/pH. The evaluation of this experiment led to the weighted mean $pK^{H}_{H_2(1,9DiMeA)} = -2.78 \pm 0.41$ (3σ) and to the following individual acidity constants at the mentioned wavelengths: 212 nm, $pK^{H}_{H(1,9DiMeA)} = -(0.77 \pm 0.11)$; 218 nm, $-(0.79 \pm 0.04)$; 220 nm, $-(0.82 \pm 0.04)$; 223 nm, $-(0.87 \pm 0.03)$; 260 nm, $-(0.84 \pm 0.23)$ (1σ), which give the weighted mean $pK^{H}_{H(1,9DiMeA)} = -(0.83 \pm 0.07)$ (3σ) for this experiment. The solid curves shown are the computer-calculated best fits at the mentioned wavelengths through the experimental data points obtained at H_0 –6.41 ([$HClO_4$] = 10.83 M), –5.96 (10.23 M), –5.52 (9.63 M), –5.07 (9.03 M), –3.78 (7.22 M), –3.78 (7.22 M), –3.78 (7.22 M), –2.85 (6.02 M), –2.47 (5.42 M), –2.13 (4.81 M), –1.52 (3.61 M), –1.18 (2.89 M), –1.08 (2.65 M), –0.86 (2.17 M), –0.63 (1.69 M), –0.36 (1.20 M), –0.10 (0.84 M), 0.05 (0.60 M), 0.25 (0.36 M), 0.46 (0.24 M), 0.79 (0.12 M), and pH 1.22, 1.64 and 1.95 (from left to right; see Section 2.5) by using the mentioned average pK_a values (25 °C; I = 0.1 M, $NaNO_3$, except in those solutions where [$HClO_4$] > 0.1 M).

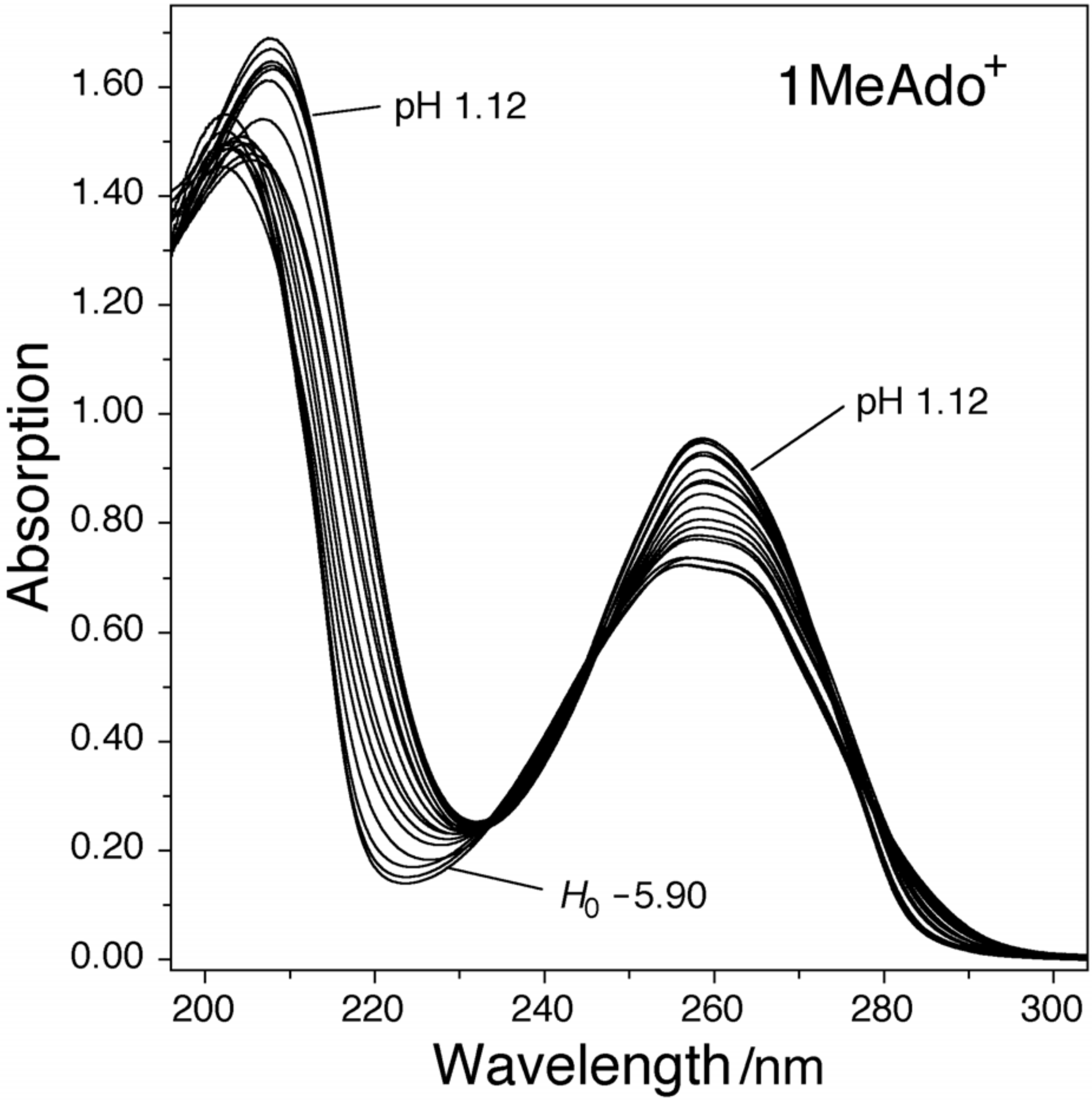

Fig. S4 UV absorption spectra of 1-methyladenosine (0.036 mM) measured in 2 cm quartz cells in aqueous solution in dependence on the activity of H^+; i.e., the H_0/pH values were varied between H_0 –5.90 to 0.59 and pH 1.12 (see legend of Fig. S5); 25 °C; $I = 0.1$ M, $NaClO_4$, except in those solutions where $[HClO_4] > 0.1$ M. Not all spectral traces of the data points which appear in Fig. S5 are shown.

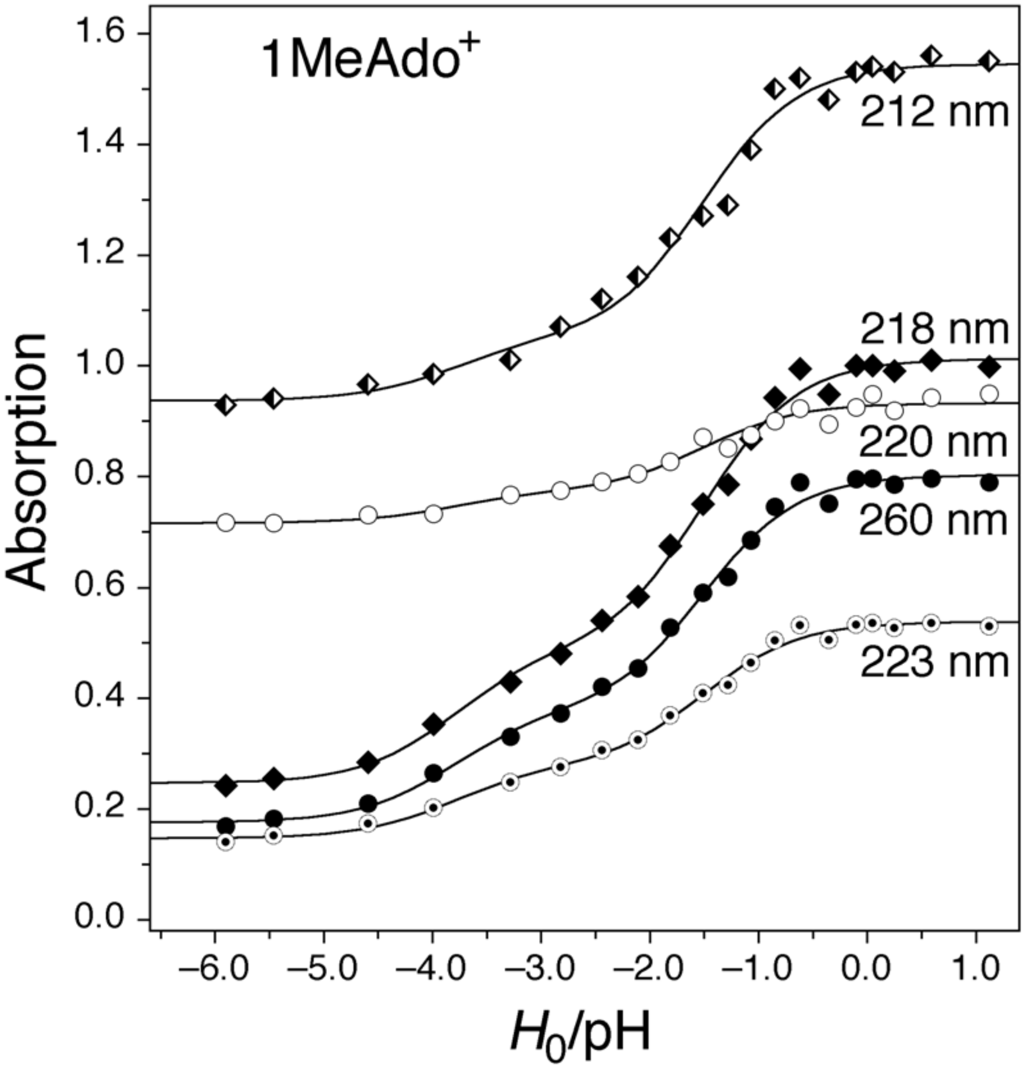

Fig. S5 Evaluation of the dependence of the UV absorption of 1-methyladenosine (1-MeAdo$^+$) at 212, 218, 220, 223 and 260 nm on the activity of H$^+$ in aqueous solution (see Fig. S4) by plotting the absorption versus H_0/pH. The evaluation of this experiment led to the weighted mean $pK^H_{H_2(1MeAdo)} = -3.81 \pm 0.28$ (3σ) and to the following individual acidity constants at the mentioned wavelengths: 212 nm, $pK^H_{H(1MeAdo)} = -(1.32 \pm 0.12)$; 218 nm, –(1.53 ± 0.06); 220 nm, –(1.53 ± 0.06); 223 nm, –(1.52 ± 0.06); 260 nm, –(1.30 ± 0.16) (1σ), which give the weighted mean $pK^H_{H(1MeAdo)} = -(1.50 \pm 0.14)$ (3σ) for this experiment. The solid curves shown are the computer-calculated best fits at the mentioned wavelengths through the experimental data points obtained at H_0 –5.90 ([$HClO_4$] = 10.15 M), –5.46 (9.55 M), –4.59 (8.36 M), –3.99 (7.52 M), –3.28 (6.57 M), –2.82 (5.97 M), –2.44 (5.37 M), –2.11 (4.78 M), –1.81 (4.18 M), –1.51 (3.58 M), –1.28 (3.11 M), –1.07 (2.63 M), –0.85 (2.15 M), –0.62 (1.67 M), –0.35 (1.19 M), –0.10 (0.84 M), 0.05 (0.60 M), 0.25 (0.36 M), 0.59 (0.18 M), and pH 1.12 (from left to right; see Section 2.5) by using the mentioned average pK_a values (25 °C; I = 0.1 M, $NaClO_4$, except in those solutions where [$HClO_4$] > 0.1 M).

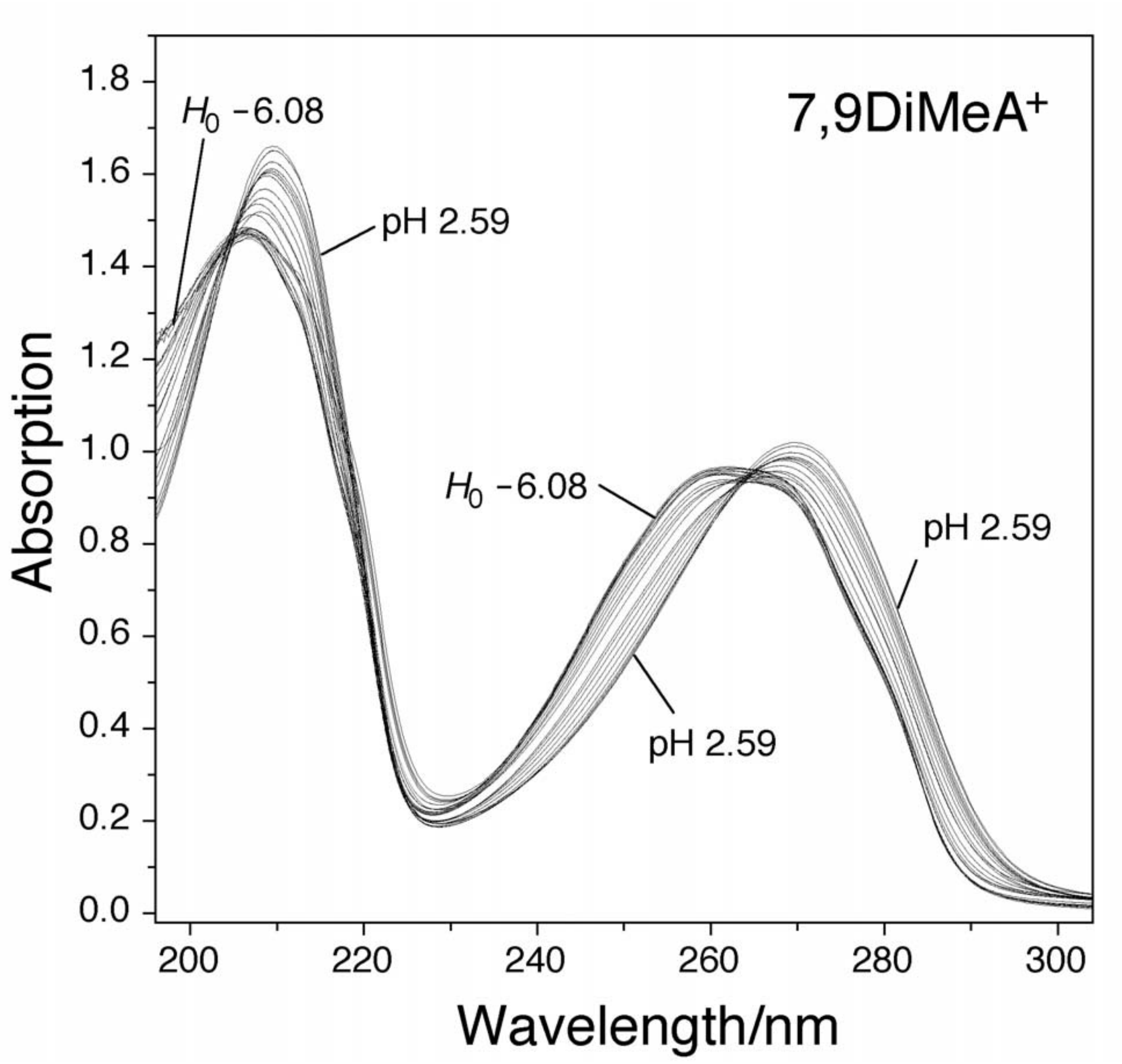

Fig. S6 UV absorption spectra of 7,9-dimethyladenine (0.037 mM) measured in 2 cm quartz cells in aqueous solution in dependence on the activity of H^+; i.e., H_0/pH values were varied between H_0 –6.08 to 0.79 and pH 0.98 to 2.59 (see legend of Fig. S7); 25 °C; $I = 0.1$ M, $NaClO_4$, except in those solutions where $[HClO_4] > 0.1$ M. Not all spectral traces of the data points which appear in Fig. S7 are shown.

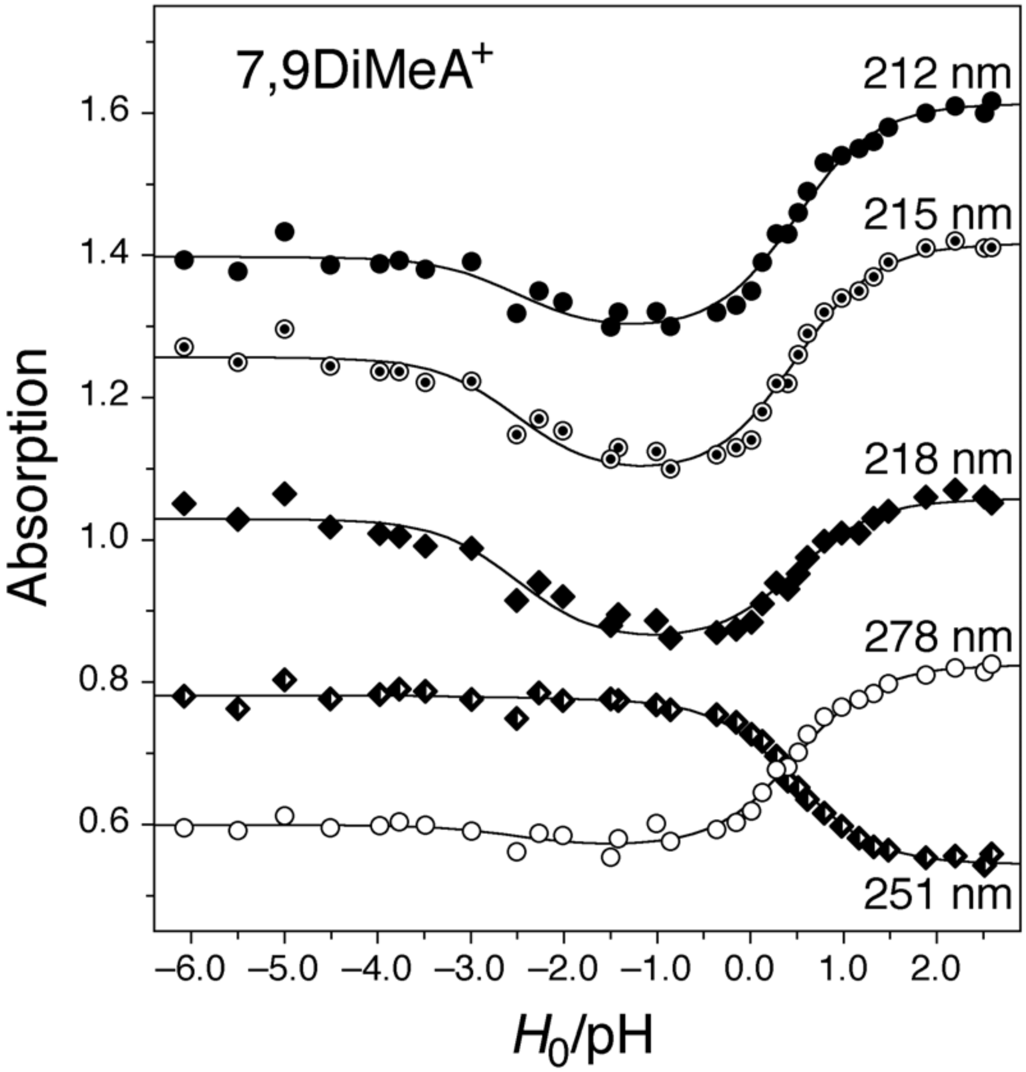

Fig. S7 Evaluation of the dependence of the UV absorption of 7,9-dimethyladenine (7,9DiMeA$^+$) at 212, 215, 218, 251 and 278 nm on the activity of H$^+$ in aqueous solution (see Fig. S6) by plotting the absorption versus H_0/pH. The evaluation of this experiment led to the weighted mean $pK^H_{H_2(7,9DiMeA)} = -2.50 \pm 0.25$ (3σ) and to the following individual acidity constants at the mentioned wavelengths: 212 nm, $pK^H_{H(7,9DiMeA)} = 0.46 \pm 0.06$; 215 nm, 0.54 ± 0.06; 218 nm, 0.63 ± 0.08; 251 nm, 0.48 ± 0.04; 278 nm, 0.47 ± 0.04 (1σ), which give the weighted mean $pK^H_{H(7,9DiMeA)} = 0.49 \pm 0.08$ (3σ) for this experiment. The solid curves shown are the computer-calculated best fits at the mentioned wavelengths through the experimental data points obtained at H_0 –6.08 ([$HClO_4$] = 10.39 M), –5.50 (9.61 M), –5.00 (8.93 M), –4.51 (8.25 M), –3.98 (7.50 M), –3.77 (7.21 M), –3.49 (6.85 M), –2.99 (6.20 M), –2.51 (5.49 M), –2.27 (5.08 M), – 2.01 (4.58 M), –1.50 (3.57 M), –1.42 (3.39 M), –1.01 (2.50 M), –0.86 (2.18 M), –0.36 (1.21 M), –0.15 (0.91 M), 0.01 (0.67 M), 0.13 (0.48 M), 0.28 (0.34 M), 0.40 (0.27 M), 0.51 (0.22 M), 0.61 (0.17 M), 0.79 (0.12 M), and pH 0.98, 1.17, 1.32, 1.48, 1.89, 2.20, 2.51 and 2.59 (from left to right; see Section 2.5) by using the mentioned average pK_a values (25 °C; I = 0.1 M, $NaClO_4$, except in those solutions where [$HClO_4$] > 0.1 M).

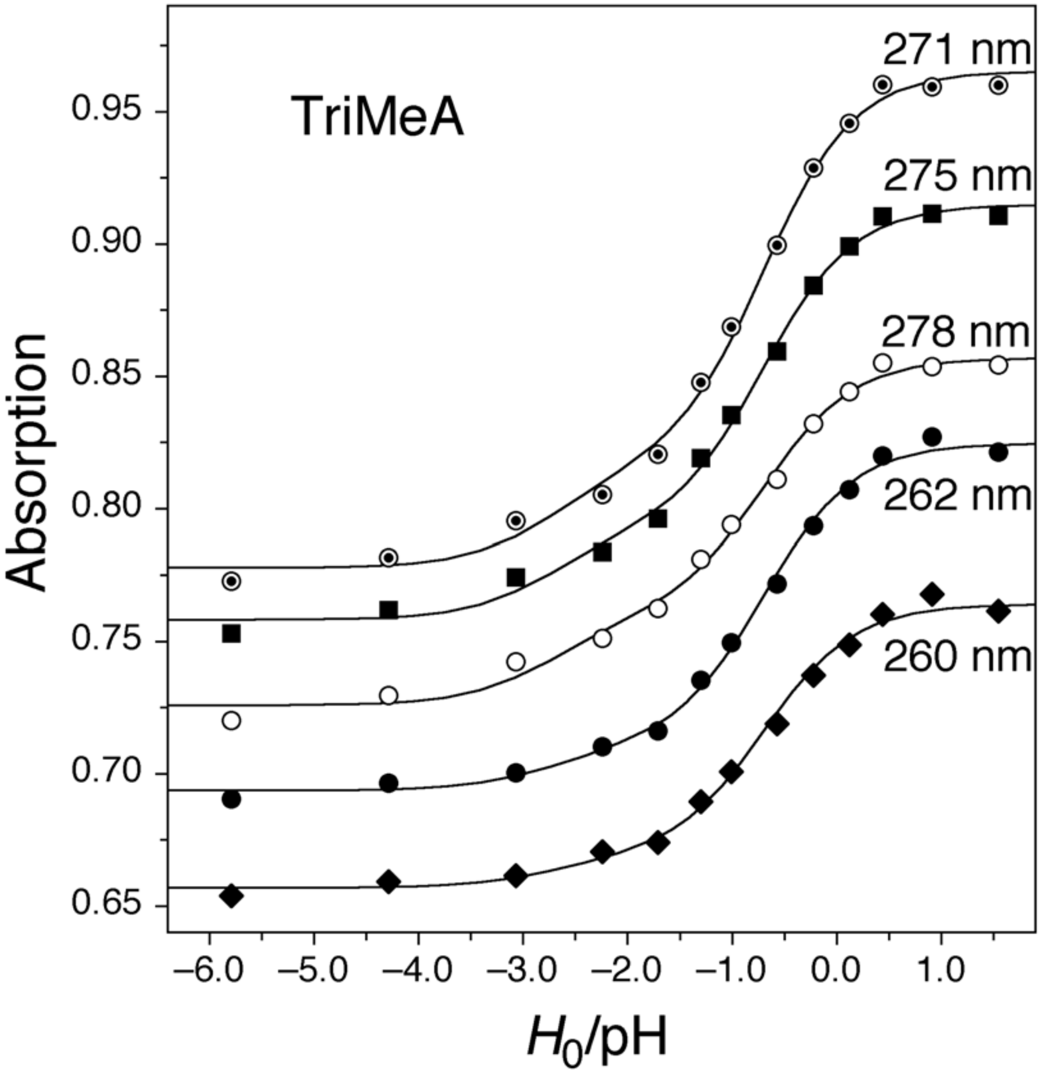

Fig. S8 Evaluation of the dependence of the UV absorption of N6',N6',N9-trimethyladenine (TriMeA) at 260, 262, 271, 275 and 278 nm on the activity of H^+ in aqueous solution by plotting the absorption versus H_0/pH (same experimental data as used in ref. 29). The evaluation of this experiment (one out of three) by keeping $pK^H_{H_3(TriMeA)} = -2.7$ constant (estimate; see Table 1) led to the following acidity constants at the mentioned wavelengths: 260 nm, $pK^H_{H_2(TriMeA)} = -(0.59 \pm 0.06)$; 262 nm, $-(0.64 \pm 0.05)$; 264 nm, $-(0.70 \pm 0.05)$ (not shown); 271 nm, $-(0.76 \pm 0.05)$; 275 nm, $-(0.73 \pm 0.06)$; 278 nm, $-(0.69 \pm 0.08)$ (1σ), which give the weighted mean $pK^H_{H_2(TriMeA)} = -(0.69 \pm 0.08)$ (3σ) for this experiment. The solid curves shown are the computer-calculated best fits at the mentioned wavelengths through the experimental data points obtained at H_0 –5.79 ([$HClO_4$] = 10.00 M), –4.29 (7.94 M), –3.07 (6.31 M), –2.24 (5.01 M), –1.71 (3.98 M), –1.30 (3.16 M), –1.01 (2.51 M), –0.57 (1.58 M), –0.22 (1.00 M), 0.12 (0.50 M), 0.44 (0.25 M), 0.91 (0.10 M), and pH 1.55 (from left to right) by using the given average pK_a values (25 °C; $I = 0.1$ M, $NaClO_4$, except in those solutions where [$HClO_4$] > 0.1 M).

$$\begin{tikzcd}
 & \text{N7-N1}{\cdot}\text{H} + \text{H}^+ \arrow[dr, "{\mathrm{p}k^{\text{N7-N1}}_{\text{N7-N1}\cdot\text{H}} = 9.57 \pm 0.05}"] & \\
{}^+\text{H}{\cdot}\text{N7-N1}{\cdot}\text{H} \arrow[ur, "{\mathrm{p}k^{\text{N7-N1}\cdot\text{H}}_{\text{H}\cdot\text{N7-N1}\cdot\text{H}} = 3.27 \pm 0.03}"] \arrow[dr, "{\mathrm{p}k^{\text{H}\cdot\text{N7-N1}}_{\text{H}\cdot\text{N7-N1}\cdot\text{H}} = 7.22 \pm 0.01}"'] \arrow[rr, "{\mathrm{p}K^{\text{H}}_{\text{H(9EtG)}} + \mathrm{p}K^{\text{H}}_{\text{9EtG}}}", "{= (3.27 \pm 0.03) + (9.57 \pm 0.05) = 12.84 \pm 0.06}"'] & & \text{N7-N1}^- + 2\text{H}^+ \\
 & {}^+\text{H}{\cdot}\text{N7-N1}^- + \text{H}^+ \arrow[ur, "{\mathrm{p}k^{\text{N7-N1}}_{\text{H}\cdot\text{N7-N1}} = 5.62 \pm 0.06}"'] &
\end{tikzcd}$$

Fig. S9 Micro acidity constant scheme for 9-ethylguanine (9EtG), where $^+\text{H}\cdot\text{N7-N1}\cdot\text{H}$ represents H(9EtG)^+ (Table 1, entry 2). The micro acidity constants (*k*) and their interrelation with the measured macro acidity constants (*K*) are defined as described in the legend for Fig. 4. Use of the value measured for 7,9DiMeG^+, $\mathrm{p}K^{\text{H}}_{\text{7,9DiMeG}} = 7.22 \pm 0.01$ (Table 1, entry 3), for the microconstant $\mathrm{p}k^{\text{H}\cdot\text{N7-N1}}_{\text{H}\cdot\text{N7-N1}\cdot\text{H}}$ permits calculation of the other microconstants in the scheme (see the third paragraph in Section 3.4).

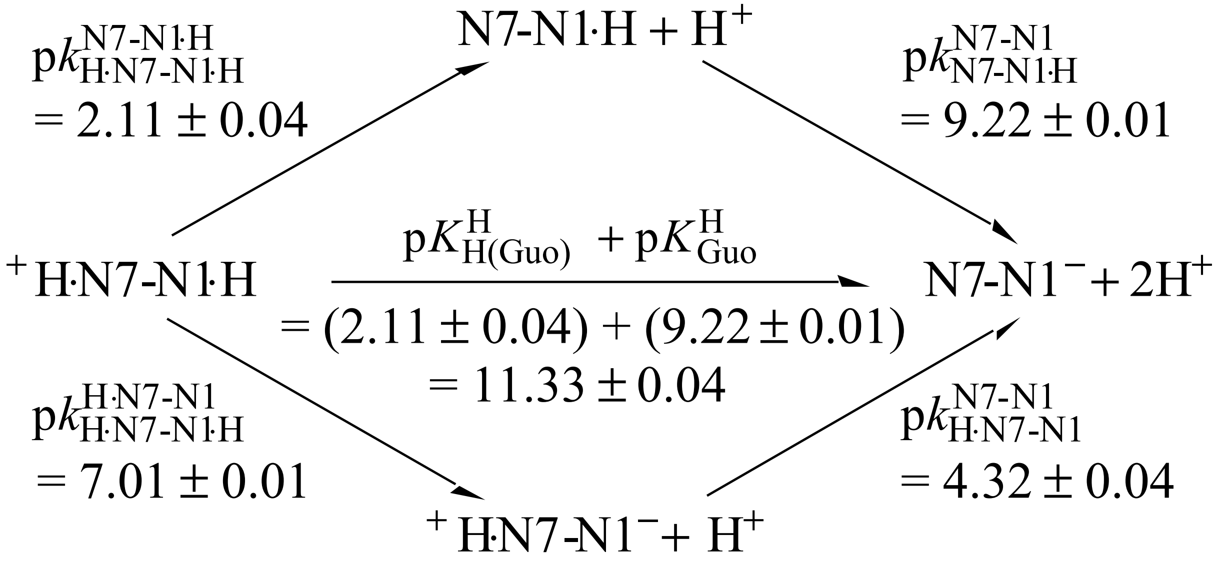

Fig. S10 Micro acidity constant scheme for guanosine (Guo), where $^+\mathrm{H\cdot N7\text{-}N1\cdot H}$ represents $\mathrm{H(Guo)}^+$ (Table 1, entry 4). The micro acidity constants (*k*) and their interrelation with the measured macro acidity constants (*K*) are defined as described in the legend for Fig. 4. Use of the value measured for $\mathrm{7MeGuo}^+$, $\mathrm{p}K^{\mathrm{H}}_{\mathrm{7MeGuo}} = 7.01 \pm 0.01$ (Table 1, entry 5), for the microconstant $\mathrm{p}k^{\mathrm{H\cdot N7\text{-}N1}}_{\mathrm{H\cdot N7\text{-}N1\cdot H}}$ permits calculation of the other microconstants in the scheme (see the fourth paragraph in Section 3.4).

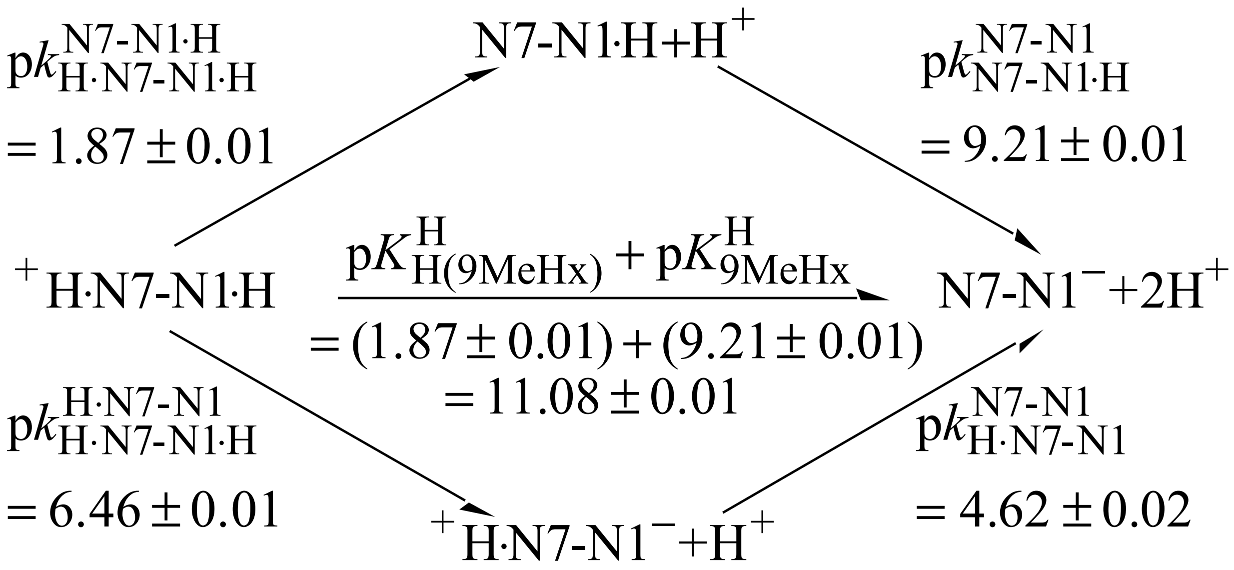

Fig. S11 Micro acidity constant scheme for 9-methylhypoxanthine (9MeHx), where $^{+}$H·N7-N1·H represents H(9MeHx)$^{+}$ (Table 1, entry 6). The micro acidity constants (*k*) and their inter-relation with the measured macro acidity constants (*K*) are defined as described in the legend for Fig. 4. Use of the value measured for 7,9DiMeHx, $\mathrm{p}K^{\mathrm{H}}_{\mathrm{7,9DiMeHx}} = 6.46 \pm 0.01$ (Table 1, entry 7), for the microconstant $\mathrm{p}k^{\text{H·N7-N1}}_{\text{H·N7-N1·H}}$ permits calculation of the other microconstants in the scheme (see the fourth paragraph in Section 3.4). The error limit of the value given for $\mathrm{p}k^{\text{N7-N1}}_{\text{H·N7-N1}}$ was deliberately enlarged from ±0.01 to ±0.02, since the latter appears to us as more realistic.

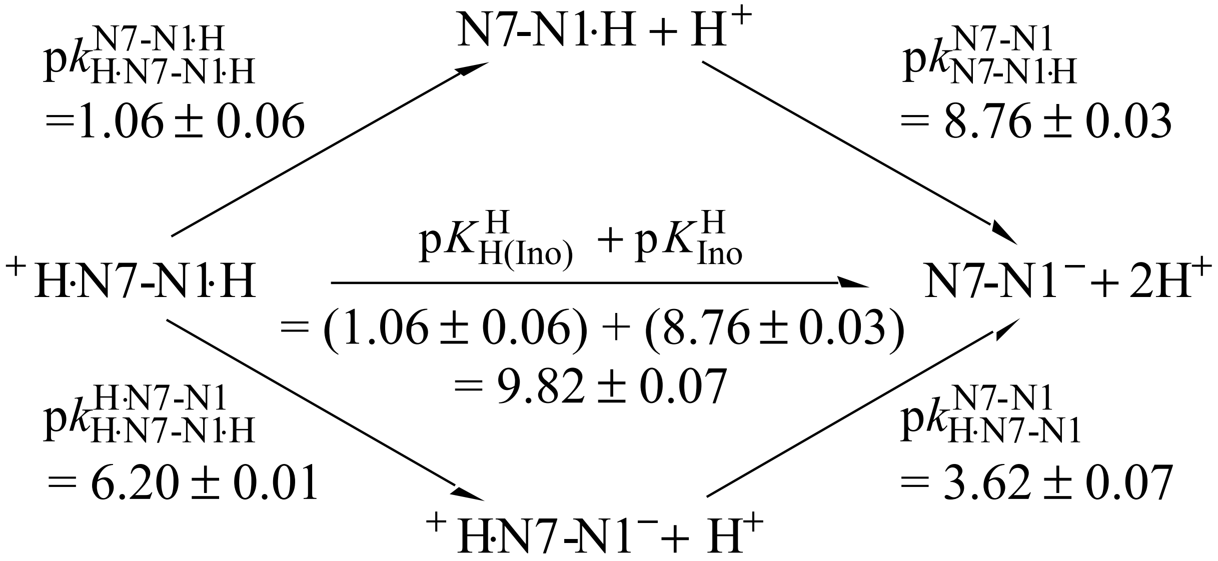

Fig. S12 Micro acidity constant scheme for inosine (Ino), where $\mathrm{^+H{\cdot}N7\text{-}N1{\cdot}H}$ represents $\mathrm{H(Ino)^+}$ (Table 1, entry 8). The micro acidity constants (*k*) and their interrelation with the measured macro acidity constants (*K*) are defined as described in the legend for Figure 4. Use of the value measured for $\mathrm{7MeIno^+}$, $\mathrm{p}K^{\mathrm{H}}_{\mathrm{7MeIno}} = 6.20 \pm 0.01$ (Table 1, entry 9), for the microconstant, $\mathrm{p}k^{\mathrm{H{\cdot}N7\text{-}N1}}_{\mathrm{H{\cdot}N7\text{-}N1{\cdot}H}}$ permits calculation of the other microconstants in the scheme (see text in Section 3.4).