Electronic Supplementary Material (ESI) for Physical Chemistry Chemical Physics.

Probing the Binding Modes and Dynamics of Histidine on Fumed Silica Surfaces by Solid-state NMR

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Supporting Information

Table S1. Sample abbreviations and preparation methods.

Abbreviation	State	Sample	Preparation
FSN	Solid	Fumed silica nanoparticles (7 nm)	When used in adsorptions, heated to 500 °C overnight prior to use
U-HisHCl	Solid, crystalline	Histidine, fully labeled, fully protonated	Isotopically labeled U-[^{15}N, ^{13}C]-L-histidine monohydrochloride monohydrate (98%). No preparation, used as received
U-His	Solid, powder	Histidine, fully labeled, zwitterionic	U-HisHCl adjusted to pH 7.6 ± 0.2 using 1M NaOH
Amorphous His	Solid, amorphous	Histidine, fully labeled, zwitterionic	The amorphous state was achieved by entrapping U-HisHCl in a sucrose solution (33% w/w) followed by flash freezing in liquid nitrogen and lyophilization
Isotropic His	Liquid	Histidine, fully labeled in an aqueous state	U-HisHCl dissolved in a 90:10 mixture of H_2O:D_2O and adjusted to pH 4 or pH 7.6 ± 0.2 using 1M NaOH
L-histidine·HCl·H_2O	Solid, crystalline	Histidine, natural abundance, fully protonated	No preparation, used as received
pure L-histidine	Solid, powder	Histidine, natural abundance, zwitterionic	No preparation, used as received
U-His/FSN-*x*	Solid, adsorbed	Histidine, fully labeled, adsorbed on FSN, *x* represents pH of the adsorption solution	U-HisHCl dissolved in water at 0.05M and adjusted to pH *x.* FSN was added and the solution was stirred for 3 h, centrifuged, and dried under vacuum
HisHCl/FSN-*x*M	Solid, adsorbed	Histidine, natural abundance, adsorbed on FSN, *x* represents concentration of the adsorption solution	L-histidine·HCl·H_2O dissolved in water at a concentration of *x*M and adjusted to pH 7.6 ± 0.2 using 1M NaOH. FSN was added and the solution was stirred for 3 h, centrifuged, and dried under vacuum
His/FSN-*x*M	Solid, adsorbed	Histidine, natural abundance, adsorbed on FSN, *x* represents concentration of the adsorption solution	Pure L-histidine dissolved in water at a concentration of *x*M and adjusted to pH 7.6 ± 0.2 using 1M NaOH. FSN was added and the solution was stirred for 3 h, centrifuged, and dried under vacuum
	"Adsorbed" or "ads"		The adsorbed layer of histidine that is in contact with FSN surface
	"Excess" or "exc"		Excess deposits of bulk histidine that build in around the adsorbed layer once the surface is saturated
	"Hydrated"		Any adsorptions that were analyzed directly following preparation and contain water at the surface
	"Dry"		Any adsorptions with the water layer removed by drying in rotor under high vacuum for 4 weeks at room temperature

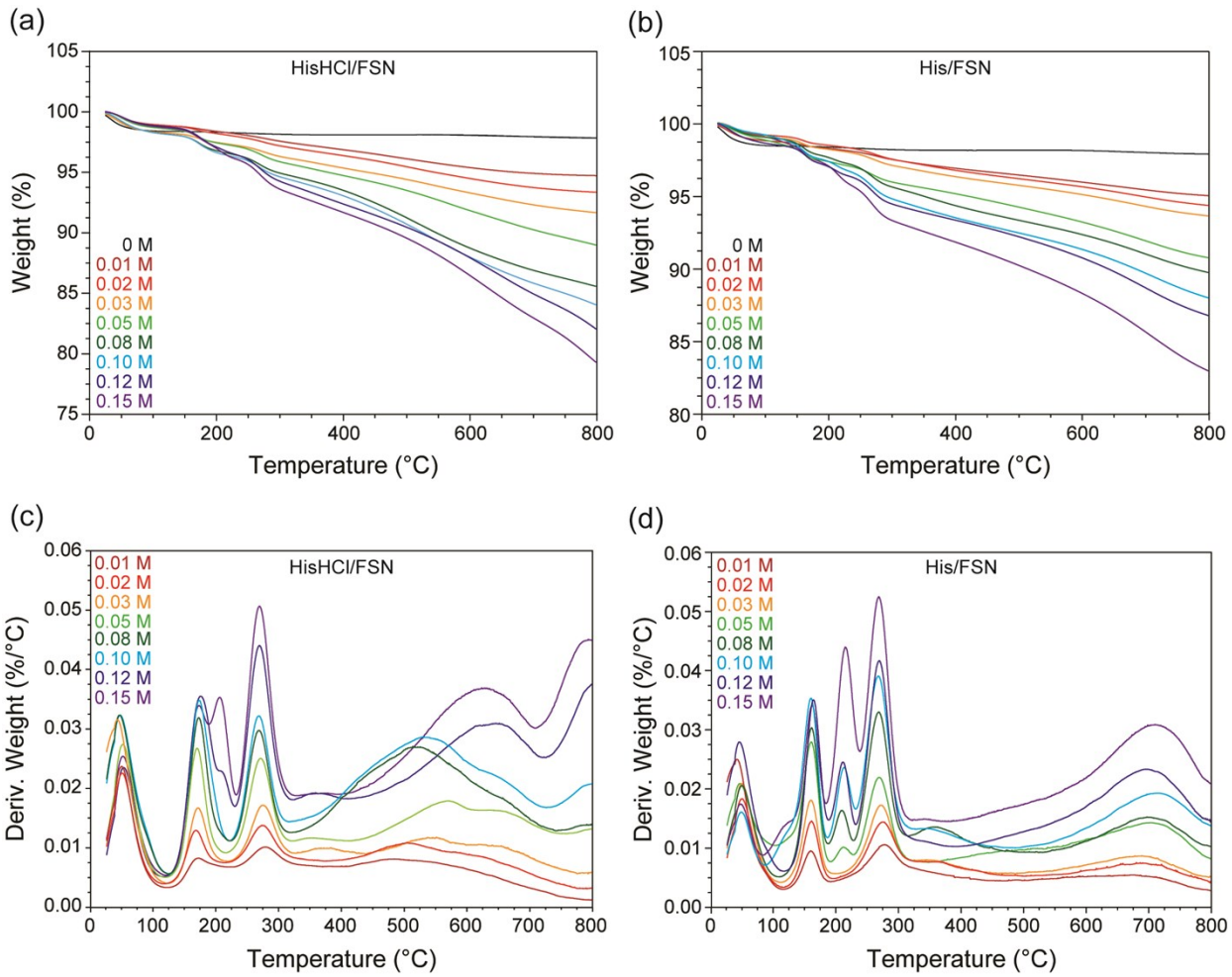

Figure S1. (a, b) TGA curves and (c, d) DTG curves of His/FSN adsorptions using natural abundance L-histidine·HCl·H_2O (fully protonated crystal) or L-histidine (neutral powder). All adsorptions were adjusted to pH 7.6 ± 0.2.

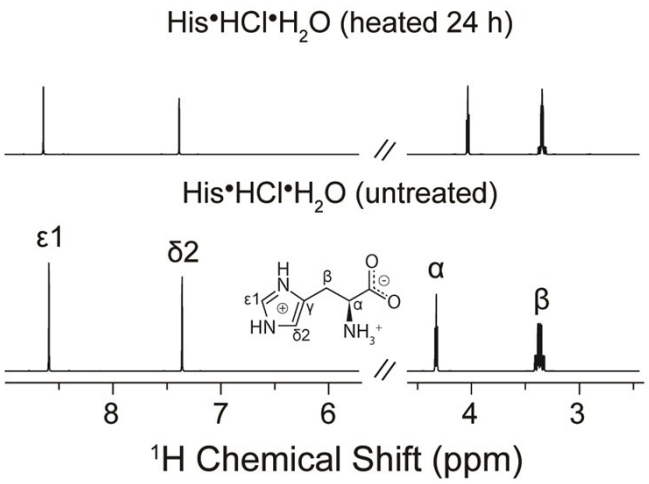

Figure S2. ^{1}H Solution NMR of free HisHCl untreated (pH 1) and free HisHCl after thermal treatment of 24 h at 165 °C (pH 4). Both samples were dissolved in 90:10 H_2O:D_2O and referenced to DSS (0 ppm) as an internal standard. The small variation in chemical shifts between the two samples is only due to pH differences between samples and not indicative of a thermal condensation product.

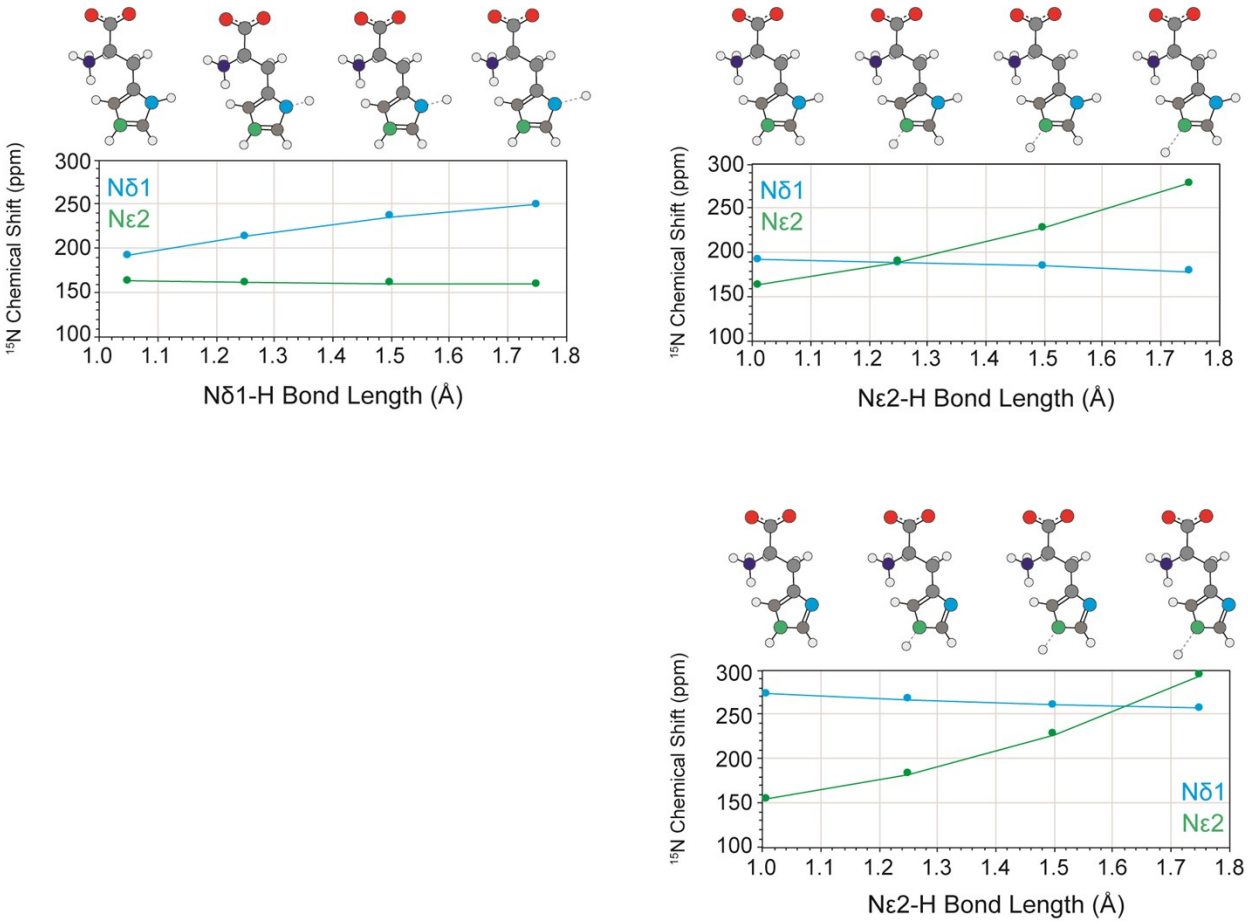

Figure S3. DFT His models with N-H perturbations and resulting NMR chemical shift calculations. The calculated ^{15}N chemical shift (ppm) is plotted as a function of N-H bond length.

Table S2. Computational results from DFT calculations of His models with N-H perturbations. A plus sign (+) represents protonated histidine with positively charged imidazole ring, and a zero (0) represents the neutral histidine molecule where $N_{\delta 1}$ has been deprotonated.

		δ_{calc} Nδ1 (ppm)	δ_{calc} Nε2 (ppm)	δ_{calc} Nα (ppm)
(+) Nδ1-H	1.05	191.8	163.2	39.1
	1.25	213.6	161.7	38.9
	1.50	235.9	160.4	38.5
	1.75	249.9	159.7	38.2
Avg Std Dev		223 ± 26	161 ± 2	39 ± 0
(+) Nε2-H	1.01	191.8	163.2	39.1
	1.25	188.7	189.7	39.3
	1.50	184.7	228.1	39.9
	1.75	179.2	278.4	41.9
Avg Std Dev		186 ± 5	215 ± 50	40 ± 1
(0) Nε2-H	1.01	272.6	154.8	44.1
	1.25	266.6	182.7	44.1
	1.50	260.2	227.2	44.1
	1.75	257.2	293.1	44.1
Avg Std Dev		264 ± 7	214 ± 60	44 ± 0

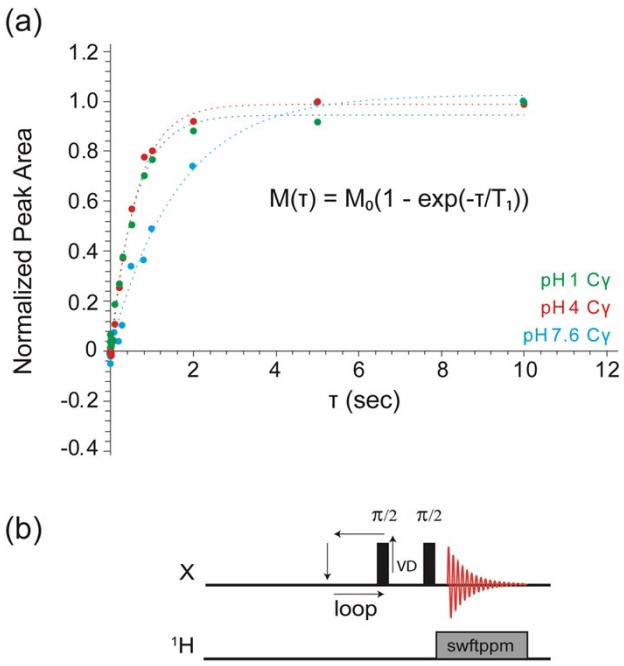

Figure S4. ^{13}C Saturation recovery experiments used to selectively measure T_1 of the adsorbed layer by using a short recycle delay. (a) Data processing displayed for C_γ sites where integrated areas are plotted and fit to a single-component equation to determine T_1. (b) The direct polarization pulse sequence of the saturation recovery experiment.

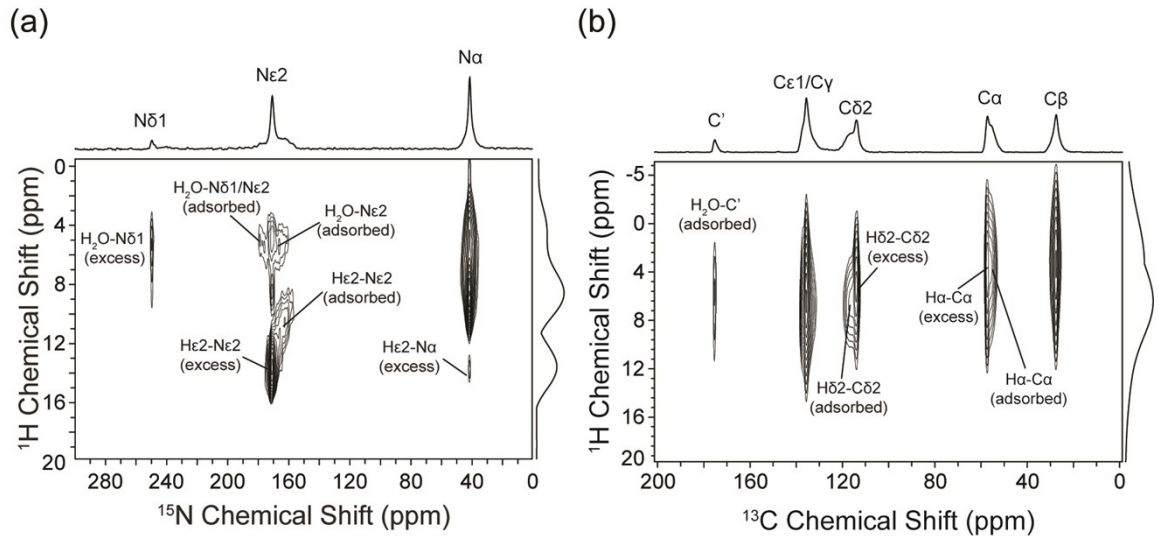

Figure S5. Full spectrum (a) ^{1}H – ^{15}N and (b) ^{1}H – ^{13}C HETCOR of U-His/FSN-7.6 in the hydrated state. Experiments were collected at 400 MHz with 35 kHz MAS. Heteronuclear correlation is observed through polarization transfer with a 1 ms contact pulse.

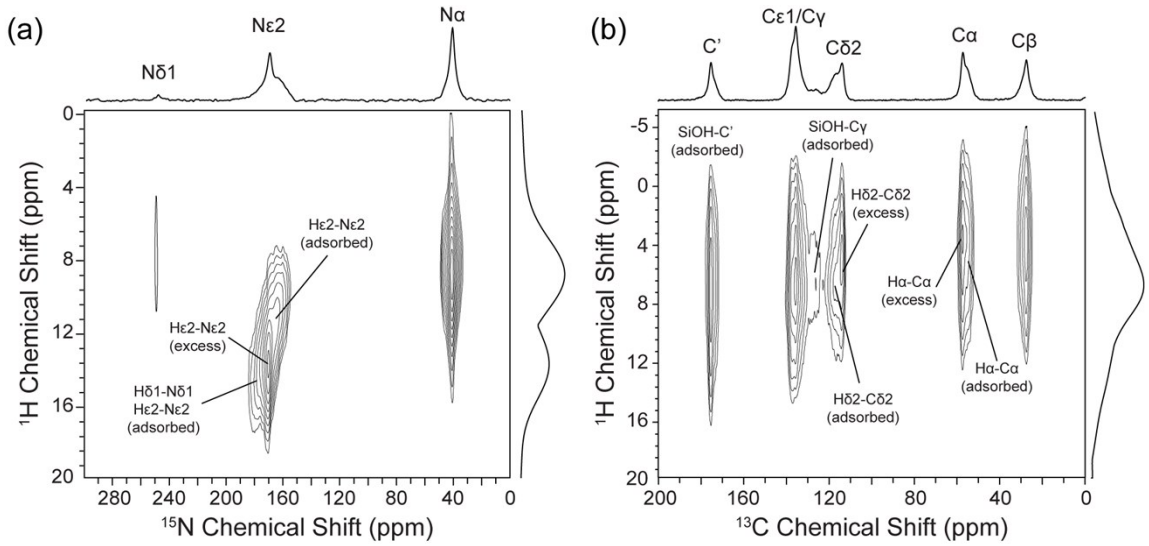

Figure S6. Full spectrum (a) ^{1}H – ^{15}N and (b) ^{1}H – ^{13}C HETCOR of U-His/FSN-7.6 in the dried state. Samples were packed in rotor and dried under high vacuum for 3 weeks. ^{1}H 1D spectra were collected before and after analysis to make sure samples did not rehydrate during experimentation. Experiments were collected at 400 MHz with 35 kHz MAS. Heteronuclear correlation is observed through polarization transfer during a 1 ms contact pulse.

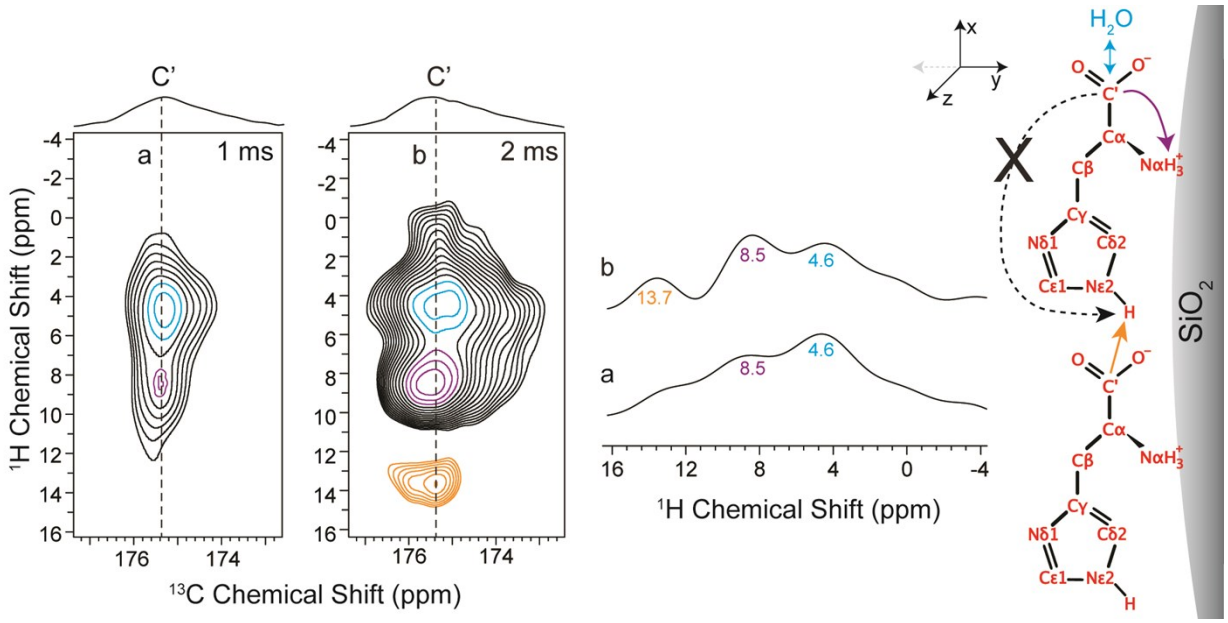

Figure S7. ^{1}H – ^{13}C HETCOR of U-His/FSN-7.6 in the hydrated state with variable CP contact time to view long range couplings. Experiments were collected at 400 MHz with 35 kHz MAS. Heteronuclear correlation is observed through polarization transfer during a (a) 1ms or (b) 2ms contact pulse. Corresponding ^{1}H slices and intermolecular interactions are illustrated on the right. This result highlights intermolecular contact between C' and Nε_2H and provides strong evidence for the horizontal arrangement of His on the FSN surface.