This version of the ESI replaces the one published on 19th April 2022 as some of the data in the tables have been corrected.

Corrected Supplementary Information

The solution structures and relative stability constants of lanthanide-EDTA complexes predicted from computation

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Content

Discussion on binding energy calculations

With the corrected experimental stability constant of the $[La^{3+}\text{-HEDTA}^{3-}\cdot(H_2O)_4]^0$ complex (see Correction), the corrected Tables S1 - S3 show a similar agreement between experiment and computation for both thermodynamic integration schemes (Eq. 1 and Eq. 2).

Corrected Table S1: Stability constants from experiment and calculated binding energies with Eq. 1. (**Corrected values in bold**)

Complex	Experimental stability constants[*]	Relative free energy of binding from experiment[**]	Relative binding energy from computation	$\varepsilon_{exp-comp}$
$[La^{3+}\text{-HEDTA}^{3-}\cdot(H_2O)_4]^0$	**7.84**	**0.50**	0.82	**32%**
$[La^{3+}\text{-EDTA}^{4-}\cdot(H_2O)_3]^-$	15.46	1 (reference)	1 (reference)	-
$[Eu^{3+}\text{-EDTA}^{4-}\cdot(H_2O)_3]^-$	17.32	1.12	1.22	10%
$[Gd^{3+}\text{-EDTA}^{4-}\cdot(H_2O)_3]^-$	17.35	1.12	1.25	12%
$[Lu^{3+}\text{-EDTA}^{4-}\cdot(H_2O)_2]^-$	19.80	1.28	1.40	13%

[*]$\log(K)$ values at 25 °C, from A.E. Martell and Robert M. Smith, "Critical Stability Constants", 1974, Plenum Press, New York.

[**]The free energies of binding were calculated from the stability constants with Eq.3.

Corrected Table S2: Stability constants from experiment and calculated binding energies with Eq. 2. (**Corrected values in bold**)

Complex	Experimental stability constants[*]	Relative free energy of binding from experiment[**]	Relative binding energy from computation[***]	$\varepsilon_{exp-comp}$
$[La^{3+}\text{-HEDTA}^{3-}\cdot(H_2O)_4]^0$	**7.84**	**0.50**	0.12	**38%**
$[La^{3+}\text{-EDTA}^{4-}\cdot(H_2O)_3]^-$	15.46	1 (reference)	1 (reference)	-
$[Eu^{3+}\text{-EDTA}^{4-}\cdot(H_2O)_3]^-$	17.32	1.12	1.18	6%
$[Gd^{3+}\text{-EDTA}^{4-}\cdot(H_2O)_3]^-$	17.35	1.12	1.27	15%
$[Lu^{3+}\text{-EDTA}^{4-}\cdot(H_2O)_2]^-$	19.80	1.28	1.04	24%

[*]$\log(K)$ values at 25 °C, from A.E. Martell and Robert M. Smith, "Critical Stability Constants", 1974, Plenum Press, New York.

[**]The free energies of binding were calculated from the stability constants with Eq.3.

Corrected Table S3: Stability constants from experiment and calculated free binding energies with Eq. S1. (**Corrected values in bold**)

Complex	Experimental stability constants[*]	Relative free energy of binding from experiment[**]	Relative free binding energy from computation	$\varepsilon_{\text{exp}-\text{comp}}$
$[\text{La}^{3+}\text{-HEDTA}^{3-}\cdot(\text{H}_2\text{O})_4]^0$	**7.84**	**0.50**	0.77	**27%**
$[\text{La}^{3+}\text{-EDTA}^{4-}\cdot(\text{H}_2\text{O})_3]^-$	15.46	1 (reference)	1 (reference)	-
$[\text{Eu}^{3+}\text{-EDTA}^{4-}\cdot(\text{H}_2\text{O})_3]^-$	17.32	1.12	1.27	15%
$[\text{Gd}^{3+}\text{-EDTA}^{4-}\cdot(\text{H}_2\text{O})_3]^-$	17.35	1.12	1.29	17%
$[\text{Lu}^{3+}\text{-EDTA}^{4-}\cdot(\text{H}_2\text{O})_2]^-$	19.80	1.28	1.58	30%

[*]$\log(K)$ values at 25 °C, from A.E. Martell and Robert M. Smith, "Critical Stability Constants", 1974, Plenum Press, New York.

[**]The free energies of binding were calculated from the stability constants with Eq.3.

We calculated free energies of binding with the following equation:

$$\Delta G_{[\text{Ln}-\text{ligand}\cdot(\text{H}_2\text{O})_n]^p} = G_{[\text{Ln}-\text{ligand}\cdot(\text{H}_2\text{O})_n]^p} - G_{\text{Ln}^{3+}} - G_{[\text{ligand}]^{(p-3)}} - n \cdot G_{\text{water}} \quad (\text{Eq. S1})$$

which uses the same scheme as Equation 1 (see method section of main text), with free energies calculated with vibrational analysis. The free energy terms were calculated with geometry optimization and frequency calculations with the M06 functional[1] using effective core potentials and corresponding basis sets (Stuttgart RSC Segmented + ECP) for the Ln^{3+} ion,[2,3] and the cc-pVTZ basis set[4] for other atoms. Vibrational frequencies of the optimized structures were obtained as well to compute free energies. Electronic structure calculations were done with ORCA, as described in the main text.

In this work (see main text), we decided to calculate relative binding energies, and not relative free binding energies, for two reasons: 1) because we are calculating relative values, and not absolute, of binding energies resulting, and 2) because predicted relative binding energies are closer to experiment that predicted relative free binding energies, which can be seen by comparing Tables S1 and S3.

(1) Zhao, Y.; Truhlar, D. G. The M06 Suite of Density Functionals for Main Group Thermochemistry, Thermochemical Kinetics, Noncovalent Interactions, Excited States, and Transition Elements: Two New Functionals and Systematic Testing of Four M06-Class Functionals and 12 Other Function. Theor. Chem. Acc. 2008, 120, 215–241.
(2) Cao, X.; Dolg, M. Valence Basis Sets for Relativistic Energy-Consistent Small-Core Lanthanide Pseudopotentials. J. Chem. Phys. 2001, 115, 7348–7355.
(3) Cao, X.; Dolg, M. Segmented Contraction Scheme for Small-Core Lanthanide Pseudopotential Basis Sets. J. Mol. Struct. THEOCHEM 2002, 581, 139–147.
(4) Dunning, T. H. Gaussian Basis Sets for Use in Correlated Molecular Calculations. I. The Atoms Boron through Neon and Hydrogen. J. Chem. Phys. 1989, 90, 1007–1023.

Energies of species used in binding energy calculations

Species	Energy (hartree)
La^{3+}	-8488.5812
Eu^{3+}	-10836.66972
Gd^{3+}	-11263.47432
Lu^{3+}	-14550.58469
$[La(H_2O)_9]^{3+}$	-9177.292833
$HEDTA^{3-}$	-1101.165644
$EDTA^{4-}$	-1100.6856
H_2O	-76.49136388
$[La^{3+}\text{-}HEDTA^{3-}\cdot(H_2O)_4]^0$	-9896.010253
$[La^{3+}\text{-}EDTA^{4-}\cdot(H_2O)_3]^-$	-9819.10396
$[Eu^{3+}\text{-}EDTA^{4-}\cdot(H_2O)_3]^-$	-12167.27132
$[Gd^{3+}\text{-}EDTA^{4-}\cdot(H_2O)_3]^-$	-12594.08722
$[Lu^{3+}\text{-}EDTA^{4-}\cdot(H_2O)_2]^-$	-15804.76046

<u>Root mean square distance analysis</u>

The first coordination spheres of the La^{3+} ion (9-coordinate) and Lu^{3+} ion (8-coordinate) were compared against ideal 9-coordinates geometries (tricapped trigonal prism, capped square antiprism) and 8-coordinate geometries (bicapped trigonal prism, square antiprism, dodecahedral), respectively, to calculate a root mean square distance (RMSD) of each simulation frame of the La^{3+} and Lu^{3+} trajectories to the ideal geometries.
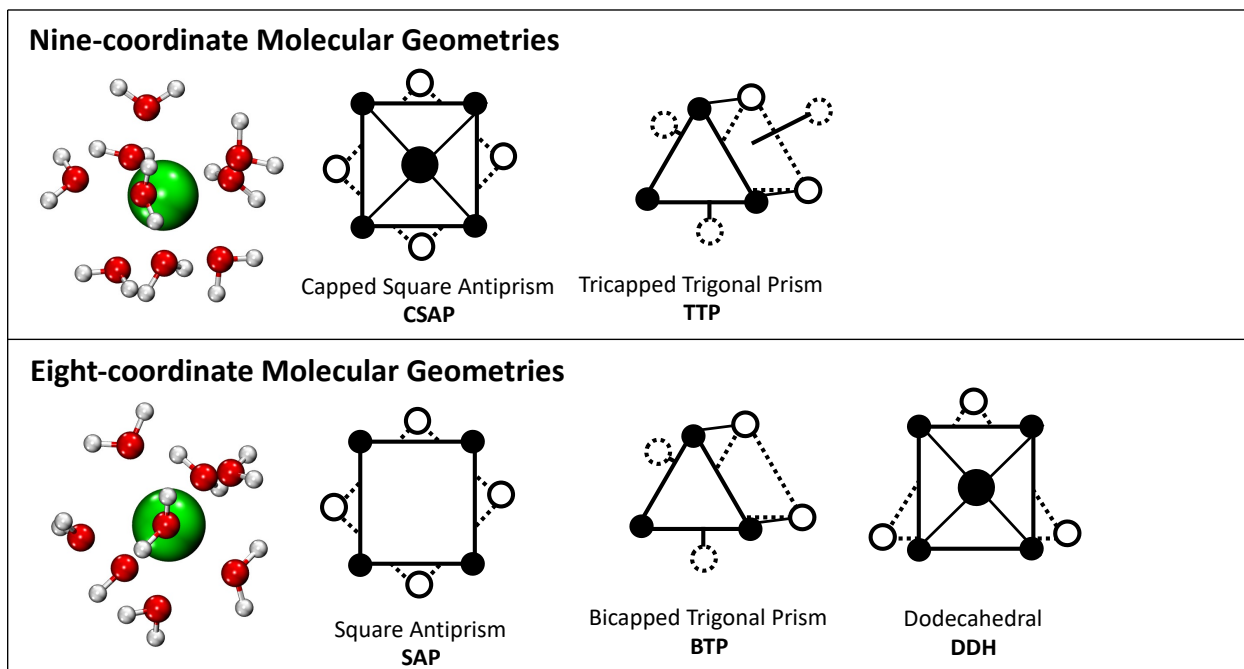

Figure S1: Ideal 9- and 8-coordinate geometries

For each frame, the RMSD to both ideal geometries were calculated as:

$$RMSD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\|a_i - b_i\|^2}$$

Where N is the number of atoms to compare (La^{3+} ion is 9-coordinate, Lu^{3+} ion is 8-coordinate), a and b are the coordinates of the ideal geometry and a frame of the AIMD trajectory to calculate the distance. The nine or eight distances between corresponding oxygen atoms (ideal and frame) are used to calculate the RMSD for each frame, and average RMSD values are obtained for the trajectory.
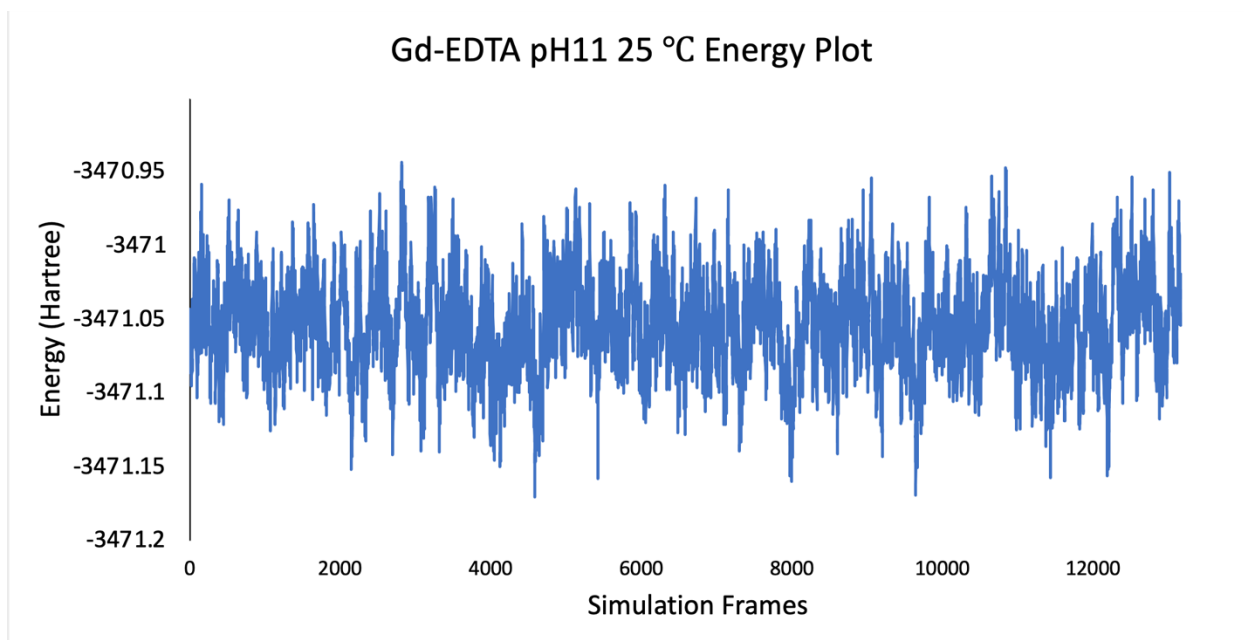
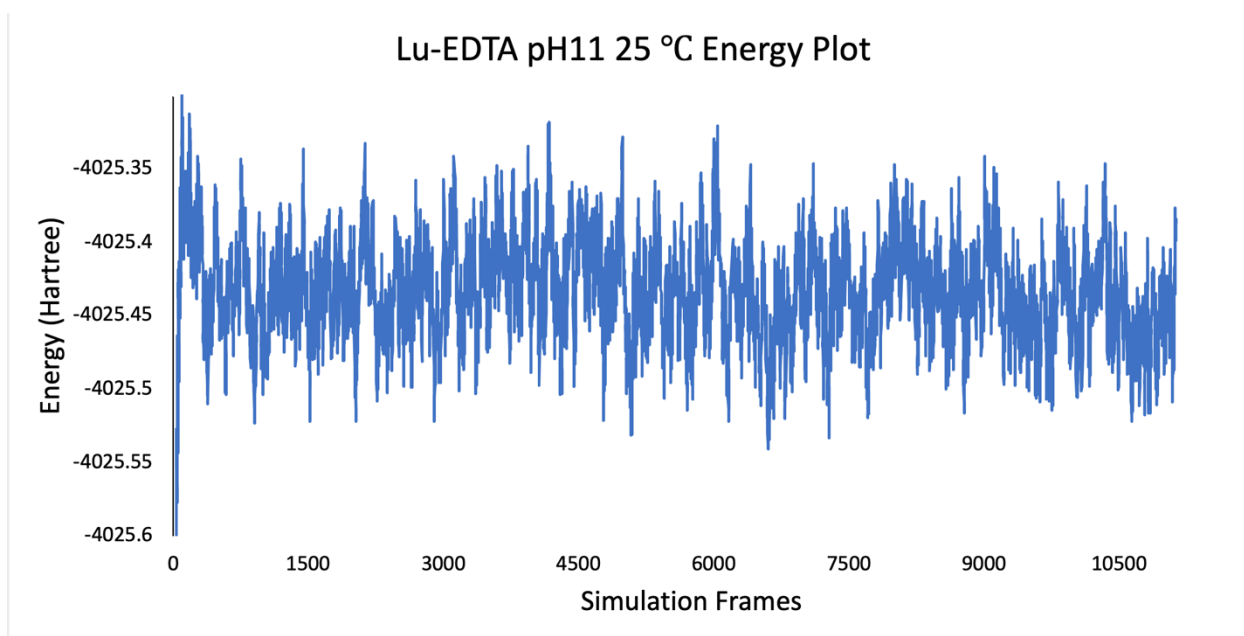## Plots of potential energy vs simulation frame
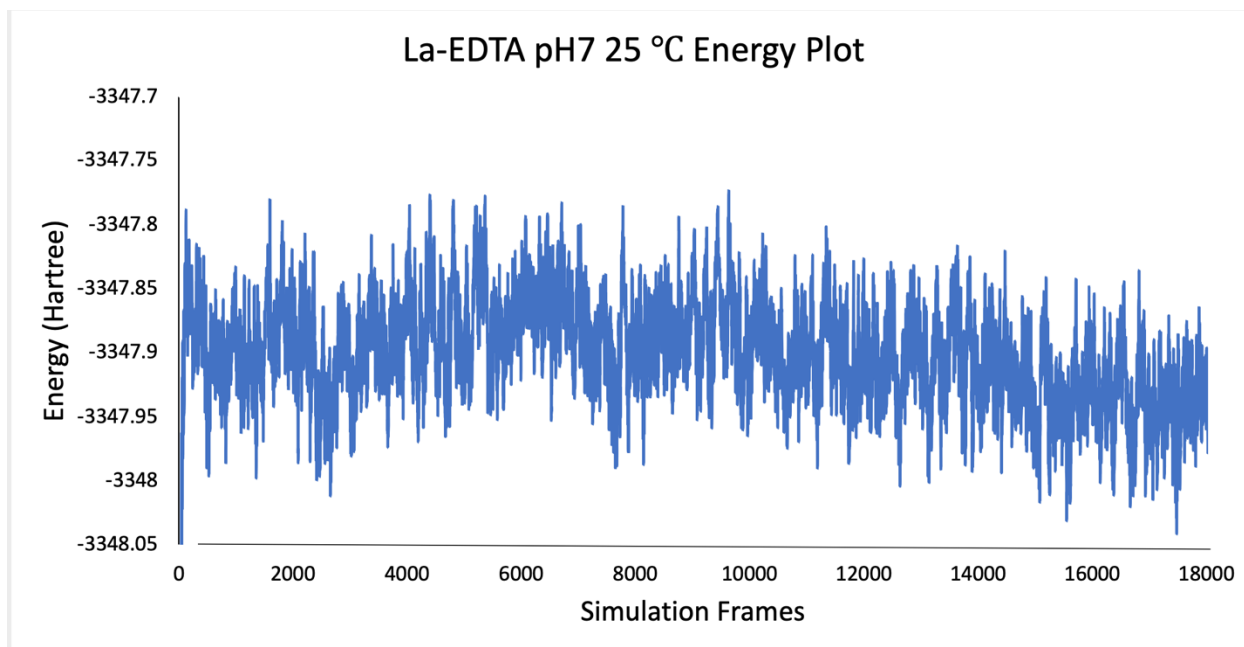
Figure S2: Energy vs. simulation frame of the $[La^{3+}\text{-}HEDTA^{3-} \cdot (H_2O)_n]^0$ complex at 25 °C.
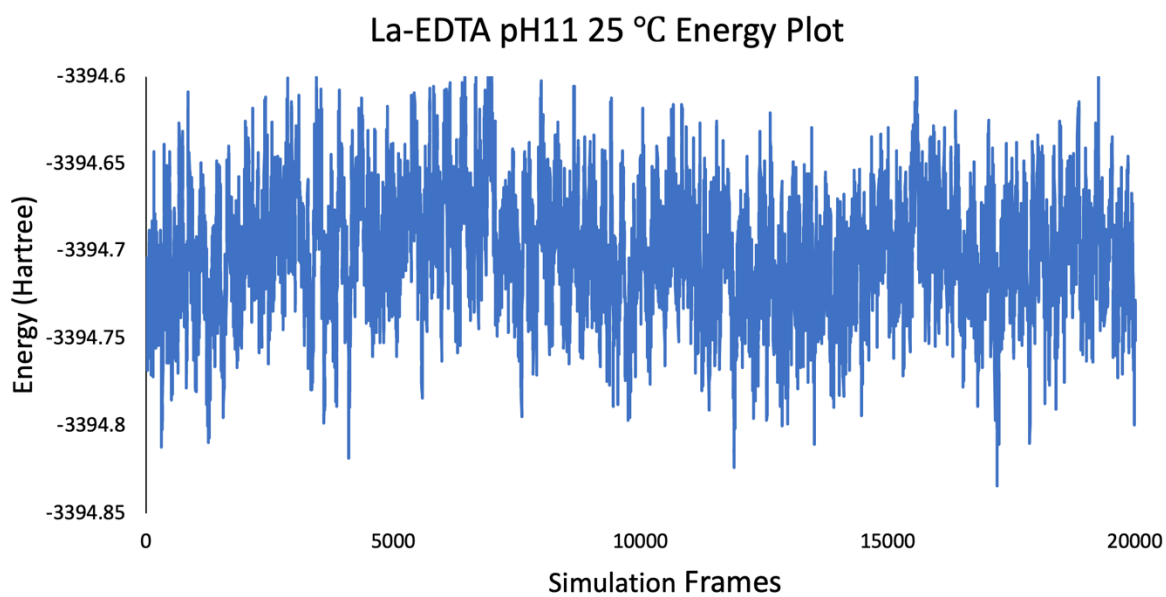
Figure S3: Energy vs. simulation frame of the $[La^{3+}\text{-}EDTA^{4-} \cdot (H_2O)_n]^-$ complex at 25 °C.
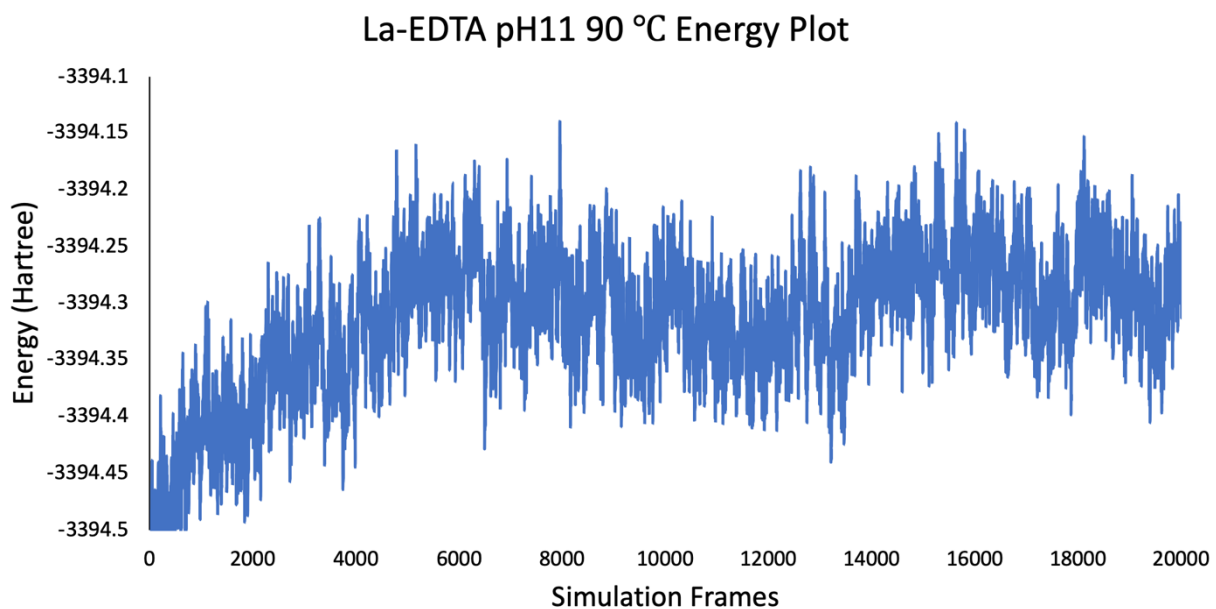
Figure S4: Energy vs. simulation frame of the $[Gd^{3+}\text{-}EDTA^{4-}\cdot(H_2O)_n]^-$ complex at 25 °C.

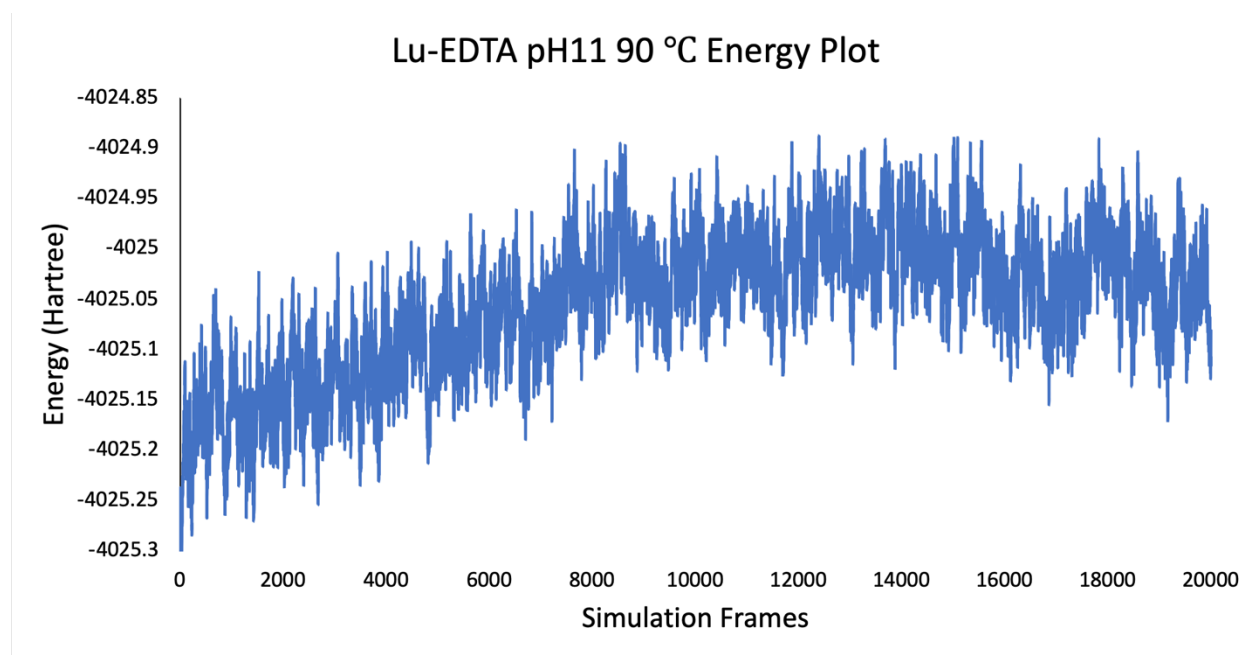**Figure S5**: Energy vs. simulation frame of the $[Lu^{3+}\text{-}EDTA^{4-}\cdot(H_2O)_n]^-$ complex at 25 °C.
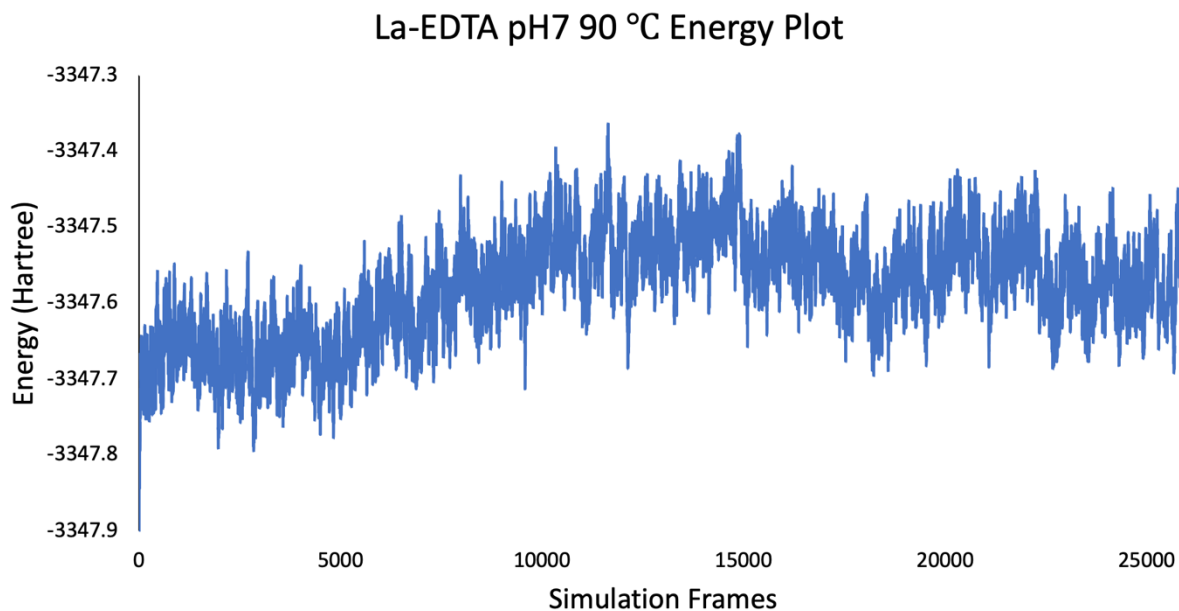
Figure S6: Energy vs. simulation frame of the $[La^{3+}\text{-}HEDTA^{3-}\cdot(H_2O)_n]^0$ complex at 90 °C.

Figure S7: Energy vs. simulation frame of the $[La^{3+}\text{-}EDTA^{4-}\cdot(H_2O)_n]^-$ complex at 90 °C.

Figure S8: Energy vs. simulation frame of the $[Lu^{3+}\text{-}EDTA^{4-}\cdot(H_2O)_n]^-$ complex at 90 °C.