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# Standard Molar Enthalpy of Formation of $[Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O$ (Hsal = Salicylate $C_7H_5O_3^-$, tch = Thioprolinate $C_4H_6NO_2S^-$)[†]

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The product from the reaction of neodymium chloride hexahydrate with salicylic acid and thioproline, $[Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O$, was synthesized and characterized by IR, elemental analysis, molar conductance, thermogravimetric analysis, and chemical analysis. The standard molar enthalpies of solution of $NdCl_3 \cdot 6H_2O(s)$, $[2C_7H_6O_3(s)]$, $C_4H_7NO_2S(s)$, and $[Nd(Hsal)2 \cdot (tch)] \cdot 2H_2O(s)$ in a mixed solvent of absolute ethyl alcohol, dimethyl sulfoxide (DMSO), and 3 $mol \cdot L^{-1}$ HCl were determined by calorimetry to be $\Delta_s H_m^{\ominus}[NdCl_3 \cdot 6H_2O(s), 298.15\ K] = -(51.94 \pm 0.14)\ kJ \cdot mol^{-1}$, $\Delta_s H_m^{\ominus}[2C_7H_6O_3(s), 298.15\ K] = (52.96 \pm 0.48)\ kJ \cdot mol^{-1}$, $\Delta_s H_m^{\ominus}[C_4H_7NO_2S(s), 298.15\ K] = (23.50 \pm 0.23)\ kJ \cdot mol^{-1}$, and $\Delta_s H_m^{\ominus}\{[Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s), 298.15\ K\} = -(41.76 \pm 0.50)\ kJ \cdot mol^{-1}$. The enthalpy change of the reaction $NdCl_3 \cdot 6H_2O(s) + 2C_7H_6O_3(s) + C_4H_7NO_2S(s) = [Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s) + 3HCl(g) + 4H_2O(l)$ was determined to be $\Delta_r H_m^{\ominus} = (172.57 \pm 0.75)\ kJ \cdot mol^{-1}$. From data in the literature, through Hess' law, the standard molar enthalpy of formation of $[Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s)$ was estimated to be $\Delta_f H_m^{\ominus}\{[Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s), 298.15\ K\} = -(2867.1 \pm 8.6)\ kJ \cdot mol^{-1}$.

## Introduction

It is known that rare earth ions and salicylic acid are antibacterial.[1−6] Thioproline possesses some special functions such as prolonging body life, controlling drug toxicity, and catalyzing plant growth and, in particular, functions as anticancer drugs, which can make cancer cells revert to normal cells.[7] The synthesis and characterization of the rare earth complexes with thioproline and salicylic acid have been reported, and their research applications in experiments were carried out on *Escherichia coli*,[8] indicating that the catalysis of the ternary complexes of rare earth ions against *Escherichia coli* was more significant than that of their ligands, thioproline, and salicylic acid. Obviously, it is very important to carry out research on the rare earth complex of thioproline and salicylic acid. The standard molar enthalpy of formation of the complex has not yet been reported. As commonly known, it is necessary to obtain basic thermodynamic properties as the basis for theoretical research and industrial design when they are synthesized and developed industrially.

In this paper, the standard molar enthalpies of solution of $[NdCl_3 \cdot 6H_2O(s)]$, $[2C_7H_6O_3(s)]$, $[C_4H_7NO_2S(s)]$, and $[Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s)$ in a mixed solvent of absolute ethyl alcohol, dimethyl sulfoxide (DMSO), and 3 $mol \cdot L^{-1}$ HCl at 298.15 K are reported. By a thermochemical cycle, the molar enthalpy of the reaction

$$NdCl_3 \cdot 6H_2O(s) + 2C_7H_6O_3(s) + C_4H_7NO_2S(s) = [Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s) + 3HCl(g) + 4H_2O(l) \quad (1)$$

and the standard molar enthalpy of formation of $[Nd(Hsal)_2 \cdot tch)] \cdot 2H_2O(s)$ were obtained.

## Experimental Section

***Chemicals and Instruments.*** The chemicals $NdCl_3 \cdot 6H_2O(s)$ (>99 %), salicylic acid $C_7H_6O_3(s)$ (>99.5 %), and KCl (>99.99 %) were obtained from the Shanghai Reagent Company. L-Thioproline ($C_4H_7NO_2S$, s) (>99.5 %) was from Wuhan University Hoyo Co., Ltd.

$NdCl_3 \cdot 6H_2O(s)$ was dried in a desiccator containing sulfuric acid (60 %)[1] at room temperature, and $C_7H_6O_3(s)$ and $C_4H_7NO_2S(s)$ were dried in a vacuum desiccator containing $P_4O_{10}$ to constant mass. KCl (calorimetric primary standard) of purity greater than 99.99 % was dried in a vacuum oven for 6 h at 135 °C.

An elemental analyzer (Perkin-Elmer 2400 CHN, USA), an FT-IR spectrometer (Avatar 360, with KBr pellets, USA), a thermogravimetric analyzer (Perkin-Elmer TG6, at a heating rate of 10 $°C \cdot min^{-1}$ flowing in $N_2$, USA), an Abbe refractometer (WAY, Shanghai, China), an ultraviolet−visible spectrotometer (U-3010, Hitachi, Japan), a solution-reaction isoperibol calorimeter (SRC 100, constructed by the thermochemical laboratory of Wuhan University, China), and a conductometer (DDS-12A, Shanghai, China) were used.

***Synthesis and Characterization of $[Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s)$.*** A mass of 0.04 mol of powdered salicylic acid $C_7H_6O_3(s)$ was dissolved in 30 $cm^3$ of absolute ethyl alcohol (solution I). Sodium salicylate solution was formed when an aqueous solution of 10 % NaOH (0.04 mol of NaOH) was added into solution I (solution II). A mass of 0.02 mol of powdered thioproline was dissolved in 50 $cm^3$ of distilled water (solution III) at 333.15 K in a water-bath. A solution mixture was obtained when solution II was added into solution III (solution IV). A mass of 0.02 mol of powdered $NdCl_3 \cdot 6H_2O$ was dissolved in 40 $cm^3$ of distilled water (solution V). White crystals were separated out when solution IV was added slowly into solution V at 333.15 K in a water-bath after 11 h of magnetic stirring. The solution was left to settle down at pH 5.0 to 6.0 over 12 h. Finally, the white

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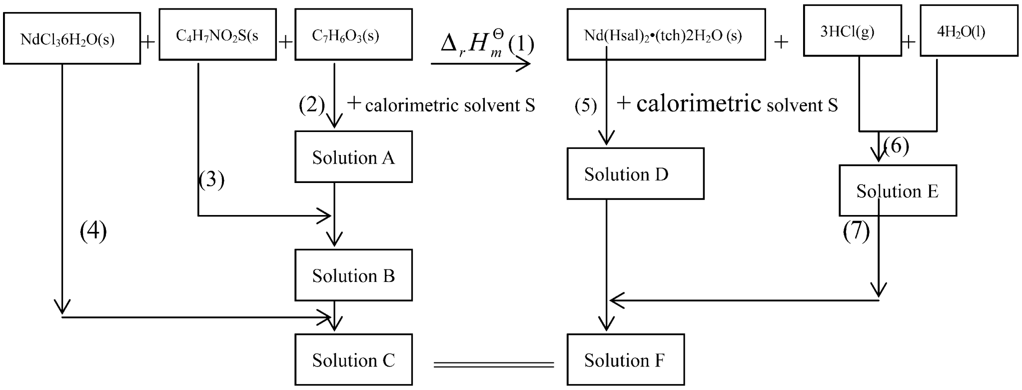

**Figure 1.** Thermochemical cycle of reaction 1.

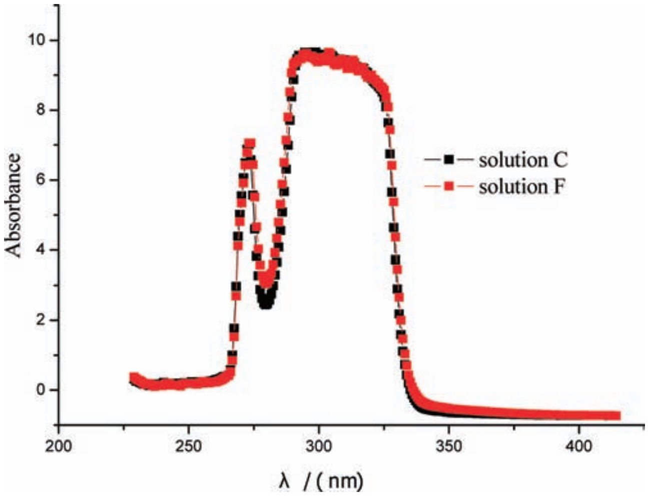

**Figure 2.** UV spectrum of the final dissolution state of the reactants and products.

solid complex was obtained by filtration in a vacuum and washed with absolute ethyl alcohol three times and several portions of hot distilled water many times at 343.15 K. The product was put into a desiccator in a vacuum at 333.15 K for 24 h and kept until the mass of the crystals became constant. The chemical composition of the synthetic sample was determined by elemental analysis for C, H, and N, by EDTA titration for $Nd^{3+}$,[9] by mercury salt titration for $Cl^-$, and by difference and TG-DTG curves for $H_2O$. The analysis results proved that the composition of the complex was $[Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s)$, and its purity was >99.1 %.

***Solution-Reaction Isoperibol Calorimety and Calibration.*** The solution-reaction isoperibol calorimeter (SRC 100) has been detailed elsewhere.[10] A Dewar vessel with an internal volume of 100 mL, equipped with a twin-blade stirrer, was submerged in the water thermostat. The precisions of temperature control and temperature measurement were ± 0.001 K and ± 0.0001 K, respectively.

The calibration of the calorimeter was carried out by measuring the dissolution enthalpies of THAM (NBS 742a, USA) in 0.0001 $mol \cdot cm^{-3}$ HCl and KCl (calorimetric primary standard) in water at 298.15 K. The mean dissolution enthalpies were (−29 776 ± 16) $J \cdot mol^{-1}$ for THAM and (17 597 ± 17) $J \cdot mol^{-1}$ for KCl, which agree with published data [(−29 766 ± 31.5) $J \cdot mol^{-1}$ for THAM[11] and (17 536 ± 9) $J \cdot mol^{-1}$ for KCl[12]].

**Table 1. Dissolution Enthalpies of $[2C_7H_6O_3(s)]$, $[C_4H_7NSO_2(s)]$, $[NdCl_3 \cdot 6H_2O(s)]$, and $[Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s)$ in the Calorimetric Solvent S at 298.15 K[a,b]**

| system | no. | $m$ (g) | $t$ (s) | $\Delta_s H_m^\ominus$ ($kJ \cdot mol^{-1}$) |
|---|---|---|---|---|
| $C_4H_7NSO_2(s)$ in S | 1 | 0.0335 | 40.74 | 23.4359 |
| | 2 | 0.0334 | 64.89 | 23.7289 |
| | 3 | 0.0334 | 67.44 | 23.7473 |
| | 4 | 0.0334 | 63.21 | 23.3491 |
| | 5 | 0.0333 | 56.16 | 23.2407 |
| $\Delta_s H_m^\ominus[C_4H_7NSO_2(s), 298.15\ K] = (23.50 \pm 0.23)\ kJ \cdot mol^{-1}$[c] | | | | |
| $2C_7H_6O_3(s)$ in the solution A | 1 | 0.0692 | 91.46 | 53..3653 |
| | 2 | 0.0692 | 81.32 | 52.2209 |
| | 3 | 0.0691 | 97.58 | 53.0947 |
| | 4 | 0.0688 | 73.79 | 53.3445 |
| | 5 | 0.0692 | 77.18 | 52.7597 |
| $\Delta_s H_m^\ominus(3) = \Delta_s H_m^\ominus[2C_7H_6O_3(s), 298.15\ K] = (52.96 \pm 0.48)\ kJ \cdot mol^{-1}$ | | | | |
| $NdCl_3 \cdot 6H_2O(s)$ in the solution B | 1 | 0.0897 | 60.66 | −51.7751 |
| | 2 | 0.0894 | 62.46 | −51.9785 |
| | 3 | 0.0897 | 51.49 | −52.1542 |
| | 4 | 0.0897 | 54.27 | −51.9229 |
| | 5 | 0.0898 | 64.23 | −51.8520 |
| $\Delta_s H_m^\ominus(4) = \Delta_s H_m^\ominus[NdCl_3 \cdot 6H_2O(s), 298.15\ K] = (21.79 \pm 0.35)\ kJ \cdot mol^{-1}$ | | | | |
| $[La(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s)$ in S | 1 | 0.1458 | 25.54 | −42.1987 |
| | 2 | 0.1457 | 51.62 | −41.8552 |
| | 3 | 0.1460 | 56.69 | −41.3876 |
| | 4 | 0.1458 | 56.91 | −42.2587 |
| | 5 | 0.1460 | 56.74 | −41.1067 |
| $\Delta_s H_m^\ominus(5) = \Delta_s H_m^\ominus[Nd(Hsal)_2 \cdot (tch) \cdot 2H_2O(s), 298.15\ K] = -(41.76 \pm 0.50)\ kJ \cdot mol^{-1}$ | | | | |
| solution D + solution E | 1 | 0.0451 | 83.17 | −66.3927 |
| | 2 | 0.0453 | 83.17 | −66.1676 |
| | 3 | 0.0441 | 83.44 | −66.4431 |
| | 4 | 0.0451 | 71.01 | −66.5198 |
| | 5 | 0.0455 | 85.24 | −66.3346 |
| $\Delta_s H_m^\ominus(7) = -(66.37 \pm 0.13)\ kJ \cdot mol^{-1}$ | | | | |

[a] $n$: molar number of sample. [b] $t$: heating period of electrical calibration. [c] Uncertainty was estimated as twice the standard deviation of the mean of the results.

**Table 2. Analytical Results of the Complex $[Nd (C_7H_5O_3)_2(C_4H_6NO_2S)] \cdot 2H_2O$ (%)**

| complex | C | H | S | N | Nd |
|---|---|---|---|---|---|
| $[Nd(C_7H_5O_3)_2(C_4H_6NO_2S)] \cdot 2H_2O$ | | | | | |
| theoretical values | 36.85 | 3.44 | 5.47 | 2.39 | 24.59 |
| experimental data | 36.71 | 3.30 | 5.88 | 2.52 | 24.37 |

***Determination of Dissolution Enthalpies.*** $[Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s)$ can be regarded as the product of the reaction 1

$$NdCl_3 \cdot 6H_2O(s) + 2C_7H_6O_3(s) + C_4H_7NO_2S(s) = [Nd(Hsal)_2 \cdot (tch)] \cdot 2H_2O(s) + 3HCl(g) + 4H_2O(l) \quad (1)$$

and the thermochemical cycle was designed as shown in Figure 1.

**Table 3. IR Absorption of Ligands and Complex ($cm^{-1}$)**

| compound | $\nu_{O-H}$ | $\nu_{C-O}$ | $\nu_{N-H}$ | $\nu_{as}^{COO^-}$ | $\upsilon_{s}^{COO^-}$ | $\delta_{N-H}$ | $\delta_{O-H}$ |
|---|---|---|---|---|---|---|---|
| $C_7H_6O_3$ | 2598 | 1663 | | | | | 1475 |
| $C_4H_7NO_2S$ | | | 3058 | 1556 | 1434 | 1632 | |
| $[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O$ | 3398 | 2922 | 1560 (1596) | 1461 (1389) | 1623 | | |

The UV spectrum and refractive indices of the final solution of the reactants and the final solution of the products can be used to determine if they have the same thermodynamic state. In the present experiments, we determined the spectrum and refractive indices of solution C and solution F and found for both of them the same UV spectrum (Figure 2) and equal refractive indices ($\eta_{25°C} = 1.4102$), which proves that both have the same thermodynamic state and that the thermochemical cycle of reaction 1 is reliable.

The chosen calorimetric solvent must dissolve the chemicals in the sample cell completely and very rapidly. The calorimetric solvent (S) of dimethyl sulfoxide (DMSO) and absolute ethyl alcohol and 3 $mol\cdot L^{-1}$ HCl ($V_{DMSO}:V_{EtOH}:V_{HCl} = 1:1:1$) is the most appropriate solvent for this experiment. Rigorous control of the stoichiometry was maintained through each series of experiments to ensure that the final solutions resulting from the dissolution of the reactants were of the same composition as those from the dissolution of the products.

The thioproline $C_4H_7NO_2S(s)$ was ground in an agate mortar, and a sample (0.033 g) was placed into a sample cell in a calorimeter. The calorimetric solvent (100 $cm^3$) was added into the reaction vessel. The calorimeter was adjusted to a constant temperature of 298.15 K, and the dissolution enthalpy was determined. A series of five experiments were performed.

$$C_4H_7NO_2S(s) + S \rightarrow \text{solution A} \tag{2}$$

where S is the calorimetric solvent (100 $cm^3$). The solution A above was kept in the reaction vessel. Powdered salicylic acid $C_7H_6O_3(s)$ (0.069 g) was put into the sample cell. A series of five experiments was performed.

$$2C_7H_6O_3(s) + \text{solution A} \rightarrow \text{solution B} \tag{3}$$

The solution B above was kept in the reaction vessel. Powdered $NdCl_3\cdot 6H_2O(s)$ (0.090 g) was put into the sample cell. A series of five experiments were performed.

$$NdCl_3\cdot 6H_2O(s) + \text{solution B} \rightarrow \text{solution C} \tag{4}$$

Powdered $[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s)$ (0.147 g) was put into the sample cell in the calorimeter, and the calorimeter solvent (100 $cm^3$) was added into the reaction vessel. The calorimeter was adjusted to a constant temperature of 298.15 K, and the dissolution enthalpy was determined. A series of five experiments were performed.

$$[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s) + S \rightarrow \text{solution D} \tag{5}$$

where S is the calorimetric solvent (100 $cm^3$). A mass of 1.5 mmol of HCl(g) was mixed into 2.0 mmol of $H_2O(l)$

$$1.5\ \text{mmol of HCl(g)} + 2.0\ \text{mmol of } H_2O(l) \rightarrow \text{solution E} \tag{6}$$

The solution D above was kept in the reaction vessel. Solution E was put into the sample cell. A series of five experiments were performed.

$$\text{solution D} + \text{solution E} \rightarrow \text{solution F} \tag{7}$$

The calorimetric results of reactions 2 to 5 and 7 are listed in Table 1.

## Results and Discussion

***Elemental Analyses and Infrared Spectra.*** Analytical results for the complex and proposed formula are given in Table 2. The determined results coincide with the theoretical ones very well.

Frequencies of characteristic absorption bands in the IR spectra ($cm^{-1}$) for the ligands and complex are given in Table 3.

There are five characteristic bands observed for salicylic acid:[13] $\nu_{OH}^{COOH}$ (hydrogen bond intramolecular, 3237 $cm^{-1}$, s), $\nu_{OH}^{COOH}$ (hydrogen bond intermolecular, 2857 $cm^{-1}$, s), $\nu_{O-H}$ (COOH, 2598 $cm^{-1}$, s), $\nu_{C-O}$ (COOH, 1663 $cm^{-1}$, vs) and $\delta_{O-H}$ (phenol, 1475 $cm^{-1}$, s). All these bands disappeared after complex formation except the band due to the angular deformation of the OH group. At the same time, two new absorption bands due to the carboxylate groups $\nu_{as}^{COO^-}$ (1594 $cm^{-1}$, s) and $\upsilon_{s}^{COO^-}$ (1387 $cm^{-1}$, s) appeared, indicating that the oxygen atoms of the carboxylate group are coordinated to the metal ion. These observed frequencies in the complex shifted to higher values when compared with the frequencies observed for the sodium salicylate salt, but $\Delta\nu(\nu_{as} - \nu_s)$ stayed the same (207 $cm^{-1}$). According to these results, it can be concluded that the carboxylate group is coordinated to the metal ion through the two oxygen atoms, as a symmetrical bidentate group.

There are four characteristic absorption bands observed for thioproline:[14] $\nu_{N-H}$ (3058 $cm^{-1}$, s, sh), $\delta_{N-H}$ (1632 $cm^{-1}$, sh),

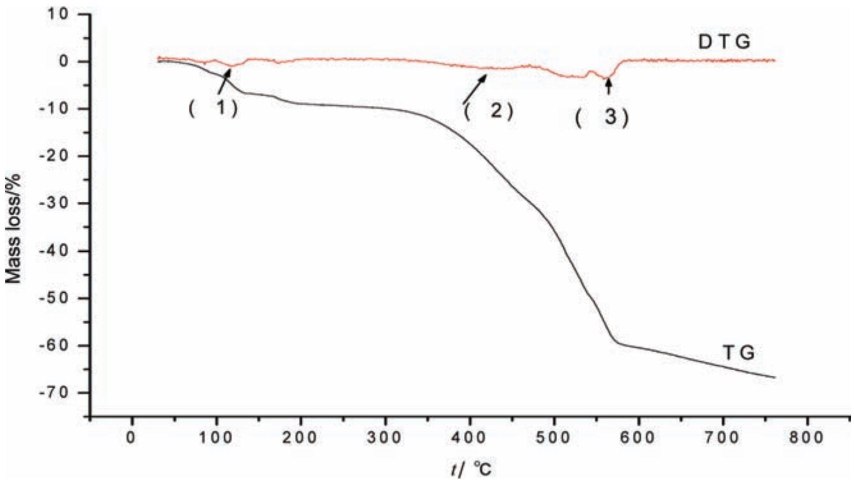

**Figure 3.** TG−DTG curves of $[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s)$.

$\nu_{as}^{COO^-}$ (1556 $cm^{-1}$, s), and $\upsilon_{s}^{COO^-}$ (1434 $cm^{-1}$, s). After complex formation, both $\nu_{N-H}$ and $\upsilon_{s}^{COO^-}$ shift toward higher frequencies $\nu_{N-H}$ (3066 $cm^{-1}$, m) and $\upsilon_{s}^{COO^-}$ (1462 $cm^{-1}$, s) and both $\delta_{N-H}$ and $\nu_{as}^{COO^-}$ shift toward lower frequencies $\delta_{N-H}$ (1622 $cm^{-1}$) and $\nu_{as}^{COO^-}$ (1548 $cm^{-1}$). According to these results, it can be concluded that the neodymium ion is coordinated with the N atom of the imine group and one O atom of the carboxylate group in thioproline, as an antisymmetric bidentate group.

***Thermal Decomposition of the Complex.*** The TG and DTG curves of $[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s)$, at a heating rate of 10 °C·$min^{-1}$ in flowing $N_2$, are shown in Figure 3. The thermal decomposition process of $[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s)$ can be divided into four stages. The first stage is from (84 to 134) °C. The TG curve shows that the mass loss corresponding to this temperature range is 6.22 %, which roughly coincides with the value of 6.14 %, calculated for the loss of 2 mol of $H_2O$ from the complex. The second stage ranges from (260 to 580) °C with the mass loss of 47.36 %, which corresponds to the loss of 2 mol of $Hsal^-$. The theoretical mass loss is 46.89 %. The third stage degradation temperature is in the range of (580 to 641) °C with the mass loss of 42.33 %, which corresponds to the loss of 1 mol of $tch^-$. The theoretical mass loss is 42.46 %. On the basis of experimental and calculated results, the thermal decomposition of $[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s)$ was postulated as follows

$$[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s) \xrightarrow{(84\text{ to }133.7)\ ^\circ C}$$

$$[Nd(Hsal)_2\cdot(tch)] \xrightarrow{(260\text{ to }580)\ ^\circ C} Nd(tch)O \xrightarrow{(580\text{ to }641)\ ^\circ C}$$

$$1/2Nd_2O_3$$

***Results of Calorimetric Experiment.*** The results of the calorimetric measurements are given in Table 1.

***Estimation of $\Delta_s H_m^\Theta(6)$.*** According to reaction 6

$$1.5\text{ mmol of }HCl(g) + 2.0\text{ mmol of }H_2O(l) \rightarrow \text{solution E}$$

$$\Delta_s H_m^\Theta(6) = \Delta_s H_m^\Theta\,(m = 41.7\text{ mol}\cdot cm^{-3}) = \Delta_s H_m^\Theta\,(m = 1.000\text{ mol}\cdot cm^{-3}) - \Delta_d H_m^\Theta(41.7 \rightarrow 1.000) = [-74.843 - (-34.923)]\text{ kJ}\cdot mol^{-1} = -39.92\text{ kJ}\cdot mol^{-1}$$

See ref 15.

***Molar Enthalpy of Reaction 1.*** According to Hess' Law, the standard molar reaction enthalpy of reaction 1 was obtained

$$\Delta_r H_m^\Theta(1) = \Delta_s H_m^\Theta(2) + \Delta_s H_m^\Theta(3) + \Delta_s H_m^\Theta(4) - \Delta_s H_m^\Theta(5) - \Delta_s H_m^\Theta(6) - \Delta_s H_m^\Theta(7) = (172.57 \pm 0.75)\text{ kJ}\cdot mol^{-1}$$

***Evaluation of $\Delta_f H_m^\Theta\{[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s)\}$.*** According to Hess' law

$$\Delta_r H_m^\Theta(1) = \Delta_f H_m^\Theta\{[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s), 298.15\text{ K}\} + 3\Delta_f H_m^\Theta[HCl(g), 298.15\text{ K}] + 4\Delta_f H_m^\Theta[H_2O(l), 298.15\text{ K}] - \Delta_f H_m^\Theta[NdCl_3\cdot 6H_2O(s), 298.15\text{ K}] - 2\Delta_f H_m^\Theta[C_7H_6O_3(s), 298.15\text{ K}] - \Delta_f H_m^\Theta[(C_4H_7NO_2S)(s), 298.15\text{ K}]$$

According to ref 16

$$\Delta_f H_m^\Theta[HCl(g), 298.15\text{ K}] = -(92.31 \pm 0.10)\text{ kJ}\cdot mol^{-1}$$

$$\Delta_f H_m^\Theta[H_2O(l), 298.15\text{ K}] = -(285.830 \pm 0.040)\text{ kJ}\cdot mol^{-1}$$

According to ref 15

$$\Delta_f H_m^\Theta[NdCl_3\cdot 6H_2O(s), 298.15\text{ K}] = -(2874.4 \pm 8.0)\text{ kJ}\cdot mol^{-1}$$

where ± 8.0 kJ·$mol^{-1}$ was calculated according to the data in refs 16 and 17. According to ref 17

$$\Delta_f H_m^\Theta[C_7H_6O_3(s), 298.15\text{ K}] = -(592.1 \pm 1.3)\text{ kJ}\cdot mol^{-1}$$

According to ref 7

$$\Delta_f H_m^\Theta[C_4H_7NO_2S(s), 298.15\text{ K}] = -(401.33 \pm 1.54)\text{ kJ}\cdot mol^{-1}$$

and the above-calculated value of

$$\Delta_r H_m^\Theta = (172.57 \pm 0.75)\text{ kJ}\cdot mol^{-1}$$

so that

$$\Delta_f H_m^\Theta\{[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s), 298.15\text{ K}\} = [172.57 - 3\cdot(-92.31) - 4\cdot(-285.830) + (-2874.4) + 2\cdot(-592.1) + (-401.33)] \pm \left[\sqrt{0.75^2 + (3\cdot 0.10)^2 + (4\cdot 0.040)^2 + (8.0)^2 + (2\cdot 1.3)^2 + (1.54)^2}\right] = -(2867.1 \pm 8.6)\text{ kJ}\cdot mol^{-1}$$

## Conclusion

In this work, $[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O$ was synthesized and characterized by IR, elemental analysis, molar conductance, thermogravimatric analysis, and chemical analysis. The enthalpy change of the reaction (eq 1) was determined to be $\Delta_r H_m^\Theta$ = (172.57 ± 0.75) kJ·$mol^{-1}$. The standard molar enthalpy of formation of $[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s)$ was estimated to be $\Delta_f H_m^\Theta\{[Nd(Hsal)_2\cdot(tch)]\cdot 2H_2O(s), 298.15\text{ K}\} = -(2867.1 \pm 8.6)$ kJ·$mol^{-1}$.

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