Electrical conductivity, differential scanning calorimetry, X-ray diffraction, and $^7$Li nuclear magnetic resonance studies of $n$-C$_x$H$_{(2x+1)}$OSO$_3$Li ($x = 12, 14, 16, 18, \text{and} 20$)

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Abstract Electrical conductivity ($\sigma$), differential scanning calorimetry (DSC), and X-ray diffraction (XRD) measurements of $n$-C$_x$H$_{(2x+1)}$OSO$_3$Li ($x = 12, 14, 16, 18, \text{and} 20$) crystals were performed as a function of temperature. In addition, $\sigma$, DSC, and XRD observations of $n$-C$_x$H$_{(2x+1)}$OSO$_3$Na and $n$-C$_x$H$_{(2x+1)}$OSO$_3$K ($x = 12, 14, 16, 18, \text{and} 20$) crystals were carried out for comparison. DSC results of the salts revealed several solid-solid phase transitions with large entropy changes ($\Delta S$). For $n$-C$_{18}$H$_{37}$OSO$_3$Li and $n$-C$_{20}$H$_{41}$OSO$_3$Li salts, each melting point produced a small $\Delta S_{\text{mp}}$ value compared with the total entropy change in the solid phases ($\Delta S_{\text{tr1}} + \Delta S_{\text{tr2}}$). Additionally, Li$^+$ ion diffusion was detected in the highest temperature solid phases. For K salts, larger $\sigma$ values were detected for potassium alkylsulfates compared with those reported for alkyl carboxylate. $^7$Li NMR spectra of $n$-C$_{18}$H$_{37}$OSO$_3$Li crystals recorded in the low-temperature phase showed large asymmetry parameters, suggesting the Li$^+$ ions are localized at asymmetric sites in the crystals.

Keywords Rotator phase · Ion conductor · $^7$Li NMR · Li salts

1 Introduction

Li$^+$ ion cells have been used recently in compact high-energy density batteries for mobile phones and computers. With the aim of further improving their safety and performance,
much effort has been devoted to the development of new solid electrolytes as replacements to the current organic and polymer solvents. One promising candidate arising from these investigations is ionic plastic crystals [1]. Plastic crystals are soft materials in the solid state, the constituents of which are isotropically rotated at each crystal-lattice point and translated into crystals. Isotropic reorientation results in small entropy changes at each melting point (ΔS_{mp} < 20 J K^{-1} mol^{-1}), and large ΔS values at the transition temperature from the low-temperature solid-phase to the plastic phase have been detected [2]. In MNO_2 crystals (where M = Li, Na, K, Rb, Cs, TI, or NH_3), compounds without Li and Na have been shown to form ionic plastic crystals with high electrical conductivity [3–24]. These facts suggest the existence of a relevant ratio of the cation and anion radii in ionic plastic crystals. The estimated ratio of the ionic radii (cation/anion) from 0.86 to 1.10 is similar to the fraction of monoatomic ions in cubic crystal systems. This condition restricts us to find new ionic plastic crystal containing Li\(^+\) ions.

Rotator crystals are classified in the family of plastic crystals. Several long-chain molecular ions often form rotator phases with monoatomic counter ions [25–42]. In this phase, two-dimensional translational self-diffusion is found as well as two-dimensional rotation about the molecular chain. In plastic crystal phases, three-dimensional rotation of molecules occurs; therefore, rotator crystals are frequently called two-dimensional plastic crystals. The thermodynamic properties of rotator crystals are similar to those of plastic crystals, e.g. small and large entropy changes have been recorded at the melting point and phase transition temperature, respectively. For n-C_x H_{(2x+1)} COOM (x = 7–21, M = Li, Na, or K), hereafter abbreviated as C_x COOM, it has been reported that some of the potential structures (12 < x) have rotator phases [43–46]. Reported differential scanning calorimetry (DSC) measurements show small entropy changes at the melting points (ΔS_{mp}) and large total entropy changes (ΔS_{total}) at solid-solid phase transition temperatures, e.g. ΔS_{mp} = 28.43 < ΔS_{total} = 38.37 J K^{-1} mol^{-1} for C15COOLi and ΔS_{mp} = 33.14 < ΔS_{total} = 49.48 J K^{-1} mol^{-1} for C17COOLi [45, 46]. Similar relationships (ΔS_{mp} < ΔS_{total}) have been reported in several n-C_x H_{(2x+1)} NH_3 Cl (x ≥ 4) (abbreviated as C_x NH_3 Cl) crystals [42]. Although C_x COOM and C_x NH_3 Cl have similar molecular structures (both compounds contain an n-alkyl group and a monoatomic ion) and form rotator phases, their electrical conductivities (σ) are different: in the C_x NH_3 Cl crystals, high σ values are detected, but C_x COOM shows low σ values. C_x COOLi shows very low σ values (< 10^{-8} S m^{-1}) until the melting point, in contrast to C_x COOK where high σ values have been reported [46].

In this study, electrical conductivity, DSC, XRD, and \(^7\)Li NMR measurements of n-C_x H_{(2x+1)} OSO_3 M (x = 12, 14, 16, 18, and 20, M = Li, Na, or K), hereafter abbreviated as C_x SO_3 M, were performed in order to obtain information about the ion conductivities of alkali metal ions by comparing physical properties of C_x SO_3 M (a strong acid due to the sulfate group) with those of C_x COOM (weak acid). To avoid even-odd effects, C_x SO_3 M crystals with even numbers of x were considered in the present study [47–49].

2 Experimental

After dissolving n-C_x H_{(2x+1)} OH (x = 12, 14, 16, 18, and 20) in benzene at 60° C, H_2SO_4 was poured into the solution to imitate the sulfonation reaction. The solution temperature was maintained at 60° C for 30 min before MOH (M = Li, Na, or K) was added. After maintaining the solution at this temperature for 2 h, the solvent was evaporated. Unreacted substances, including the products, were removed by washing with ethanol.
DSC thermograms were recorded with a Shimadzu DSC-60 calorimeter using an Al$_2$O$_3$ reference. The samples were heated at a rate of 5 K min$^{-1}$. Electrical conductivity measurements were performed at 1 kHz using a two-terminal method by employing an Andou AG-4303 LCR meter equipped with an Al sheet. The powdered sample was pressed into a disc that was 1 cm in diameter and ca. 1 mm thick. For the measurements, the air around the probe was replaced by dry N$_2$ gas. X-ray diffraction (XRD) patterns were obtained at various temperatures using a Bruker D8 ADVANCE equipped with a Cu anticathode. The measurements were performed by employing a rotating stage at room temperature and a ttk450 probe at additional temperatures. Spectra were recorded using a scan range of 5–40$^\circ$ with a step angle of 0.02$^\circ$. Solid-state $^7$Li ($I = 3/2$) NMR spectra were recorded at a Larmor frequency of 233.23 MHz using a Bruker Avance 600 spectrometer (14.10 T). The samples were packed in a ZrO$_2$ rotor with an outer diameter of 4.0 mm. The magic-angle-spinning (MAS) method at 1 kHz was employed throughout the free-induction-decay (FID) acquisition. $^7$Li MAS NMR and $^7$Li NMR spectra were obtained by Fourier transformation of the FID signals recorded after a single pulse ($\pi/4$ pulse). $^1$H decoupling pulse sequences were applied to the $^7$Li MAS NMR and $^7$Li NMR measurements. In addition, $^7$Li NMR spectra without $^1$H decoupling pulses revealed dipole-dipole interactions between $^7$Li and $^1$H nuclei. $^1$H NMR spectra were also recorded at a Larmor frequency of 600.13 MHz with the same spectrometer in order to confirm that the products were prepared with high purity. The products were dissolved into DMSO solvent and poured into a glass tube with a 5.0 mm diameter.

Computations were carried out using the Gaussian 03 program [50] to estimate the charge distribution in the anions. The B3LYP/6-31+G** level of theory was employed for the optimization of the anions. The charge distribution was calculated at the B3LYP/6-311+G** level of theory.

3 Results and discussion

DSC thermograms observed above room temperature for C$_x$SO$_3$Li, C$_x$SO$_3$Na, and C$_x$SO$_3$K are displayed in Fig. 1. In these thermograms, the variation appearing around 300
Table 1  Entropy changes at each transition temperature and melting point

<table>
<thead>
<tr>
<th></th>
<th>$\Delta S_{tr2}(T_{tr2})$</th>
<th>$\Delta S_{tr1}(T_{tr1})$</th>
<th>$\Delta S_{mp}(T_{mp})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C12SO$_3$Li</td>
<td></td>
<td>42.6 (413.4)</td>
<td>24.5 (508.4)</td>
</tr>
<tr>
<td>C14SO$_3$Li</td>
<td></td>
<td>50.2 (420.0)</td>
<td>151.9 (487.2)</td>
</tr>
<tr>
<td>C16SO$_3$Li</td>
<td></td>
<td>35.2 (414.9)</td>
<td>161.0 (484.1)</td>
</tr>
<tr>
<td>C18SO$_3$Li</td>
<td>29.8 (332.1)</td>
<td></td>
<td>42.0 (469.5)</td>
</tr>
<tr>
<td>C20SO$_3$Li</td>
<td>44.2 (330.0)</td>
<td></td>
<td>43.7 (473.1)</td>
</tr>
<tr>
<td>C12SO$_3$Na</td>
<td>21.2 (370.8)</td>
<td>3.3 (470.9)</td>
<td>40.9 (485.4)</td>
</tr>
<tr>
<td>C14SO$_3$Na</td>
<td>43.7 (343.7)</td>
<td>5.1 (386.0)</td>
<td>5.8 (464.0)</td>
</tr>
<tr>
<td>C16SO$_3$Na</td>
<td>30.8 (344.2)</td>
<td>16.9 (396.3)</td>
<td>20.0 (430.2)</td>
</tr>
<tr>
<td>C18SO$_3$Na</td>
<td>30.2 (348.9)</td>
<td>21.6 (401.8)</td>
<td>11.8 (425.2)</td>
</tr>
<tr>
<td>C20SO$_3$Na</td>
<td>5.9 (358.6)</td>
<td>3.3 (402.2)</td>
<td>4.2 (421.9)</td>
</tr>
<tr>
<td>C12SO$_3$K</td>
<td>27.2 (340.0)</td>
<td>4.2 (493.4)</td>
<td>50.4 (489.8)</td>
</tr>
<tr>
<td>C14SO$_3$K</td>
<td>59.8 (351.7)</td>
<td>6.2 (485.3)</td>
<td>99.3 (503.9)</td>
</tr>
<tr>
<td>C16SO$_3$K</td>
<td>103.6 (363.2)</td>
<td>19.7 (388.0)</td>
<td>24.7 (523.0)</td>
</tr>
<tr>
<td>C18SO$_3$K</td>
<td>103.7 (351.7)</td>
<td>21.9 (391.8)</td>
<td>74.7 (524.5)</td>
</tr>
<tr>
<td>C20SO$_3$K</td>
<td>160.6 (344.9)</td>
<td>23.1 (389.1)</td>
<td>–</td>
</tr>
</tbody>
</table>

Unit of entropy and temperature are given in J K$^{-1}$ mol$^{-1}$ and K, respectively.

K is due to instrument noise. Herein, the symbols $T_{tr1}$, $T_{tr2}$, . . . , are employed for the transition temperature from higher temperatures in the solid phase, and Phase I, Phase II, . . . , are named for the solid phases of the higher temperatures. Complex signals were recorded on DSC spectra of C20SO$_3$Li, C14SO$_3$Na, C12SO$_3$K, and C14SO$_3$K. Since XRD and NMR spectra weren’t uniquely obtained in the phase of narrow temperature range, the symbols of Phase I, Phase II, . . . , are used for phases with temperature ranges > 20 K. In the case of C20SO$_3$Li, entropy changes at the melting point ($\Delta S_{mp}$) and transition temperatures ($\Delta S_{tr1}$ and $\Delta S_{tr2}$) were estimated by the line-area from 473 to 515 K, 405 to 430 K, and 330 to 360 K, respectively. In C14SO$_3$Na, C12SO$_3$K, and C14SO$_3$K each $\Delta S_{tr}$ value was determined the area from 343 to 375 K, from 489 to 540 K, and from 504 to 547 K, respectively. $\Delta S_{mp}$ and $\Delta S_{tr}$ values of whole salts treated in this study are listed in Table 1. The melting points recorded for CxSO$_3$Li and CxSO$_3$K are similar to those reported for CxCOOLi and CxCOOK [46], respectively. In contrast, no decomposition signals were observed in CxSO$_3$Na, although it has been reported that several CxCOONa crystals decompose rather than fuse at high temperatures around 500 K [46]. For CxSO$_3$Li, small $\Delta S_{mp}$ values compared with the total entropy changes in the solid phases ($\Delta S_{tr1} + \Delta S_{tr2}$) were recorded for C18SO$_3$Li and C20SO$_3$Li; conversely, large $\Delta S_{mp}$ values were detected for C14SO$_3$Li and C16SO$_3$Li. This result suggests that molecules gain a large freedom of motion in Phase I of C18SO$_3$Li and C20SO$_3$Li crystals. For C12SO$_3$Li, a small $\Delta S_{mp}$ value compared with those of C18SO$_3$Li and C20SO$_3$Li was observed; therefore, it also can be expected that molecular motions with large amplitudes are present in the C12SO$_3$Li crystal. For the Na and K salts, small $\Delta S_{mp}$ values compared with total entropy changes in the solid phases were recorded for CxSO$_3$Na ($x \geq 14$) and C16SO$_3$K. Conversely, large $\Delta S_{mp}$ values.
Electrical Conductivity and $^7$Li NMR Studies of $C_x$SO$_3$Li

were detected for C14SO$_3$K and C18SO$_3$K. In order to gain information about the crystal structures of C$_x$SO$_3$Li, XRD measurements were performed.

Temperature dependences of XRD powder patterns observed in C$_x$SO$_3$Li, crystals are shown in Fig. 2. The patterns recorded for Phase I, II, and III of C18SO$_3$Li and C20SO$_3$Li showed similar line patterns to the those reported for C$_x$COOK (13 ≤ $x$ ≤ 21), which forms rotator phases. The difference between Phase I and the other phases was the signal intensities: the peak counts in the 15–30° range reduced above a $T_{tr1}$ of ca. 420 K. This decrease can be linked to free rotation about the alkyl chain. A similar trend is reported in rotator crystals [46]. Based on our DSC and XRD measurements, it can be considered that molecules undergo free rotation about the long-chain axis in Phase I of C18SO$_3$Li and C20SO$_3$Li. In order to reveal the symmetry of the crystal structures, $^7$Li NMR measurements were carried out.

The $^7$Li NMR spectra observed for the C18SO$_3$Li crystal are displayed in Fig. 3. The line shape of the spectra recorded with $^1$H decoupling pulse sequences showed first order interactions of quadrupole coupling, as displayed in Fig. 3a, where the signal of the central

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**Fig. 2** Temperature dependences of XRD patterns in C$_x$SO$_3$Li ($x = 12, 14, 16, 18,$ and 20) crystals
Fig. 3  $^7$Li NMR spectra showing (a) the temperature dependences of static spectra observed with $^1$H decoupling pulses, (b) MAS NMR spectrum recorded at room temperature with $^1$H decoupling pulses, (c) the temperature dependences of static spectra observed without any decoupling pulse, and (d) theoretical curves convoluted at 170 Hz

transition between 1/2 and -1/2 was observed at 0 kHz and two satellite-peaks between ±3/2 and ±1/2 were recorded around 16 and -16 kHz. Since the line shapes of the satellites show characteristic indications of quadrupole interactions with the non-zero asymmetry parameter ($\eta$), Li$^+$ ions can be considered to be localized at low symmetry sites in the C18SO$_3$Li crystal. Employing a MAS speed of 1 kHz with $^1$H decoupling pulse sequences produced spinning sidebands on the central line of the $^7$Li MAS NMR signal, as shown in Fig. 3b. This result indicates that the line-width of the central peak is affected by dipole-dipole and/or chemical-shift anisotropy (CSA) interactions. In these measurements, $^1$H decoupling pulse sequences were used in accumulating the FID data; therefore, the dipole-dipole interactions among $^7$Li and $^1$H nuclei hardly contribute to the spectrum. In addition, abundant spins of other present atoms ($^{12}$C, $^{16}$O, $^{32}$S, and $^{34}$S) have no nuclear moments, and the CSA of Li$^+$ ions is generally small because a Li$^+$ ion has only two electrons in the s-orbital with an angular momentum of zero. Based on these facts, the line-width of the $^7$Li NMR signal observed at 0 kHz can be considered to be mainly caused by dipole-dipole interactions among $^7$Li nuclei. The full-width at half maximum (FWHM) of 170±3 Hz for the $^7$Li static NMR spectrum was estimated at room temperature. The line width can be estimated by the Li–Li distance ($r$) in the following relation:

$$\Delta \nu \approx \frac{\gamma^2_{^7Li}}{\pi r^3} \hbar$$

Here $\Delta \nu$ and $\gamma$ are the FWHM and gyromagnetic ratio, respectively. By substituting 170±3 Hz for $\Delta \nu$ in the equation, $r = 476±3$ pm is obtained. This length is similar to the reported halogen-halogen distances in a rotator crystal that consists of a two-dimensional double-layered lamella-type structure formed with rod-like alkyl ammonium and halogen ions stacked alternately along the crystallographic long-axis [26, 27].
In order to obtain information about the interaction between the anion and Li$^+$ ion, $^7$Li NMR measurements without $^1$H decoupling pulse sequences were carried out. The obtained
Table 2 $e^2 Qqh^{-1}$ and $\eta$ values simulated in $n$-C$_{18}$H$_{37}$OSO$_3$Li

<table>
<thead>
<tr>
<th>Temperature / K</th>
<th>$e^2 Qqh^{-1}$ / kHz</th>
<th>$\eta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>9.55</td>
<td>0.69</td>
</tr>
<tr>
<td>310</td>
<td>8.79</td>
<td>0.65</td>
</tr>
<tr>
<td>320</td>
<td>8.60</td>
<td>0.63</td>
</tr>
<tr>
<td>330</td>
<td>8.47</td>
<td>0.61</td>
</tr>
<tr>
<td>340</td>
<td>8.41</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Fig. 5 Electrical conductivity of (a) C$_x$SO$_3$Li, (b) C$_x$SO$_3$Na, and (c) C$_x$SO$_3$K ($x = 12, 14, 16, 18, \text{ and } 20$) crystals as a function of temperature.

spectra are shown in Fig. 3c. A similar FWHM of 174±3 Hz was detected for the central peak as that recorded with $^1$H decoupling pulse sequences (Fig. 3a), suggesting that dipole-dipole interactions acting on the Li$^+$ ion from the H atoms are minor, i.e. the distance between the Li$^+$ ion and alkyl group is long. In ionic rotator crystals, lamella-type crystal structures are frequently observed [26, 27]. Our XRD and $^7$Li NMR measurements
suggest the C18SO$_3$Li crystal form lamella-type crystal structures (Li$^+$ ions form layered structures with an -OSO$_3^-$ terminal anion adjacent to the layer) as shown in Fig. 4. In order to obtain information about Li$^+$ ion sites, we performed a line-shape simulation of the $^7$Li NMR spectra, in which the line shapes were convoluted by Lorentzian broadening at 170 Hz (dipole-dipole interactions between the Li$^+$ ions were applied). The simulated lines are plotted in Fig. 3d and the obtained $e^2 Q q h^{-1}$ and $\eta$ values are summarized in Table 2. Both $e^2 Q q h^{-1}$ and $\eta$ gradually decreased with increasing temperature, although dipole-dipole interactions among Li$^+$ ions were independent of temperature (the line width of the central peak was independent of temperature). In lamella-type crystal structures, the principal axis (zz component) of the electrical-field-gradient (EFG) of the $^7$Li nucleus lies along the molecular chain (parallel to the c-axis of a tetragonal structure), with xx and yy directions of the EFG perpendicular to the molecular chain. In this structure, the nearest Li$^+$ ions are
located horizontally to the Li$^+$ ion. The decreasing $e^2 Q q h^{-1}$ values with increasing temperature suggest that interactions between Li$^+$ and alkyl sulfate ions reduce with temperature. In contrast, the minuscule change in dipole-dipole interactions among Li$^+$ ions suggests that the distance between Li$^+$ ions rarely changes with temperature. This tendency is consistent with our XRD results displayed in Fig. 2: the signal recorded at ca. 6° slightly decreased with temperature (this peak can be attributed to the (001) reflection). In contrast, the lines detected from 15 to 30° were independent of temperature (these peaks contain information about the plane perpendicular to the c-axis).

In order to detect ionic diffusion in the solid phases of C$_x$SO$_3$Li, electrical conductivity ($\sigma$) measurements were carried out. The obtained results are plotted in Fig. 5. The C18SO$_3$Li and C20SO$_3$Li crystals showed $\sigma$ values of $10^{-7} - 10^{-5}$ S cm$^{-1}$. In contrast, large resistances were observed in other lithium salts of C$_x$SO$_3$Li ($x = 12, 14,$ and 16). Since $\sigma$ values have rarely been obtained in rotator crystals with only Li$^+$ cations [46], the observable $\sigma$ values of C18SO$_3$Li and C20SO$_3$Li salts are unique. In the lower temperature phases (Phase II and III) of C18SO$_3$Li and C20SO$_3$Li, ionic diffusion could not be recorded.
Thus, it can be assumed that Li\(^+\) ion diffusion occurs if the crystal transforms to the rotator phase. Additionally, \(\sigma\) values were detected in \(\text{CxSO}_3\text{Na}\) (\(12 \leq x \leq 16\)) and \(\text{CxSO}_3\text{K}\) (\(12 \leq x \leq 20\)) crystals and plotted in Figs. 5b and c, respectively. XRD patterns observed in these compounds are displayed in Fig. 6. The XRD patterns showed that these crystals, besides \(\text{C20SO}_3\text{K}\), have no rotator phases, indicating that ionic diffusion of Na\(^+\) and K\(^+\) can be observed even if the crystals do not transform to the rotator phase. This difference can be explained by the charge density on the surface of Li\(^+\) and K\(^+\) ions: a large surface charge in Li\(^+\) acts as a strong inter-ionic force to attract the anion. For \(\text{C20SO}_3\text{Li}\) crystals, the \(\sigma\) values increased ca. \(10^3\) times compared with those reported in \(\text{C21COOK}\) solids \[46\]. In order to estimate the interaction between the cations and anions, the charge distributions in \(n\)-\(\text{C}_{20}\text{H}_{41}\text{OSO}_3^-\) and \(n\)-\(\text{C}_{21}\text{H}_{41}\text{COO}^-\) ions were simulated using the Gaussian 03 software package. Before charge distribution calculations, atomic arrangements of both anions were optimized at the B3LYP/6-31+G** level of theory. Then B3LYP/6-311+G** was applied to estimate charge densities to give \(-0.456\) and \(-0.499\) at the terminal O atom of \(n\)-\(\text{C}_{20}\text{H}_{41}\text{OSO}_3^-\) and \(n\)-\(\text{C}_{21}\text{H}_{41}\text{COO}^-\), respectively. This result is consistent with the \(\sigma\) values recorded for \(\text{C20SO}_3\text{Li}\) and reported for \(\text{C21COOLi}\) \[46\]. A large negative charge at the terminal O atom can attract cations with a stronger force; therefore, Li\(^+\) ions can be considered to be localized in the \(\text{C21COOLi}\) crystal and mobile in \(\text{C20SO}_3\text{Li}\).

4 Conclusions

Electrical conductivity, DSC, and XRD measurements \(n\)-\(\text{C}_x\text{H}_{(2x+1)}\text{OSO}_3\text{Li}\) solids \((x = 12, 14, 16, 18,\) and \(20)\) were performed as a function of temperature. Our results revealed that \(n\)-\(\text{C}_{18}\text{H}_{37}\text{OSO}_3\text{Li}\) and \(n\)-\(\text{C}_{20}\text{H}_{41}\text{OSO}_3\text{Li}\) form rotator phases with \(\sigma\) values up to \(10^{-6}\) S cm\(^{-1}\). Since high \(\sigma\) values have rarely been reported in rotator crystals containing only Li\(^+\) cations, the data obtained in this study is quite unique. In addition, higher \(\sigma\) values were recorded in \(n\)-\(\text{C}_{20}\text{H}_{41}\text{OSO}_3\text{K}\) crystals compared with those of \(n\)-\(\text{C}_{21}\text{H}_{39}\text{COOK}\). DFT simulations at the B3LYP/6-311+G** level of theory demonstrated that the terminal O atom of alkyl sulfate has a low charge density compared with that of alkyl carboxylate. This trend explains the high \(\sigma\) values of \(n\)-\(\text{C}_{20}\text{H}_{41}\text{OSO}_3\text{Li}\) and \(n\)-\(\text{C}_{20}\text{H}_{41}\text{OSO}_3\text{K}\) compared with those of the corresponding carbonates. \(^7\text{Li}\) NMR spectra revealed that Li\(^+\) ions are localized at asymmetric sites in the low temperature phases of the rotator crystals, indicating that Li\(^+\) ion diffusion can be recorded only in the rotator phase.

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References


