
Ionic Behaviour in Sodium Based Solid Electrolytes

*ShivenduTripathi and **Subodh Kumar Sharma

*Satish Chandra College, Ballia

**S.S.V. College Hapur

ABSTRACT

Rechargeable batteries not only have the ability to effectively transform chemical energy into electrical energy, but they also have the capacity to store the chemical energy that is produced. Lithium-ion batteries (LIB) have lately come to dominate the markets for portable electronic gadgets, electric autos, and hybrid electric vehicles. This is mostly attributable to the lithium-ion battery's high output voltages, high energy densities, and extended cycle life. Despite the fact that its high cost and the lack of readily available supplies of lithium limit its applicability in large-scale energy storage, LIB has recently been dominating both of these markets. One potential alternative to lithium-ion batteries is the sodium-ion battery, more commonly referred to as a SIB. SIBs have performance levels that are comparable to LIBs and include a significant amount of salt in addition to starting ingredients that are quite affordable. As a result of the fact that the sodium atom is considerably larger and more substantial than the lithium atom, it is not predicted that the gravimetric and volumetric energy density of a sodium-ion battery will be greater than that of a lithium-ion battery. The actual as well as conceptual aspects of the conduction of lithium ions via SPEs have been the subject of a significant amount of research. The current emphasis on lithium solid-state batteries is justified because of the well-known transport capabilities of Li⁺ ions; nevertheless, the continuous extraction and utilisation of this metal will almost certainly result in the long-term unavailability of this resource. This emphasis is justified by the well-known transport capabilities of Li⁺ ions. In order to satisfy the enormous demand that is presently there, it is likely that new polymer electrolytes that are based on a variety of mobile ions might be developed. Because they are abundant in nature and their integration into electrode materials is on par with that of other ions, Na⁺ ions are an ideal choice to consider.

Keywords: Sodium , Solid , Electolytes , Ionic , Thermal , Behavior

INTRODUCTION

Energy storage for applications of sustainable energy is becoming an increasingly critical requirement as a consequence of the growth in global energy demand as well as the rising knowledge of the harmful environmental repercussions of burning fossil fuels. This is because energy storage for applications of sustainable energy is becoming an increasingly critical necessity as a result of the increase in global energy demand. This is due to the startling increase in the amount of energy that has been used. This is due to the fact that it is becoming increasingly important for applications that employ sustainable energy to have the capability to store energy on a global scale. As a result of the various benefits offered by lithium ion batteries, these types of batteries are quickly becoming the standard for nearly all portable electronic devices. They feature incredibly small ionic sizes, which enable fast material transport; extraordinarily negative redox potentials, which result in high cell voltage; and light weights, which enable high specific energy devices. All of these properties contribute to the high cell voltage. All of these characteristics have a role in the high cell voltage and high specific energy levels that lithium ion batteries are

capable of. Because of these positive characteristics, lithium ion batteries have become more popular.[1-4]

Lithium ion batteries

There is a good chance that the lithium ion batteries (LIBs) that currently dominate the market for portable gadgets will also be used to power the next generation of electric automobiles. This is a very exciting prospect. LIBs offer the highest energy density and output voltage of all the many types of rechargeable batteries that are currently available. Even though there are a lot of advantages to using LIBs, the great majority of the world's lithium resources are located in South America. However, the scant lithium deposits in that region are not enough to satisfy the growing demand for lithium in the country's many different types of enterprises.[5-7]

High availability in nature and similarity in the insertion process into electrode materials thanks to sodium battery component optimisation

As a potential alternative to lithium-ion batteries (also known as LIBs), sodium-ion batteries, also known as SIBs, are now being investigated as a viable option. Sodium is the fourth most common element found in the crust of the Earth; it is also non-toxic, and its cost is far lower than that of lithium. A great number of investigations, both experimental and theoretical, have been carried out in order to have a better understanding of how lithium ions may move through SPEs. Although the current emphasis on lithium solid-state batteries has been justified by the well-known transport capabilities of Li^+ ions, the continued extraction and utilisation of this metal will surely result in its long-term unavailability. This is despite the fact that the transport capabilities of Li^+ ions have been known for quite some time. The fact that the transport characteristics of Li^+ ions are generally recognised will not serve as an acceptable justification for the lack of availability. To satisfy such a significant demand, new polymer electrolytes that are built on top of ions that are more mobile may be manufactured. Na^+ ions are an excellent option because they are simple to get in nature and can be included into electrode materials in a manner that is analogous to how other ions may be incorporated. Recently, there has been a lot of focus placed on the optimisation of sodium battery components; nonetheless, there are still significant issues with ion transport that need to be overcome.[8-9]

Typical Sodium-Ion Battery Thermal Runaway Process

The phenomenon known as thermal runaway can occur when there is a positive feedback loop involving heat, temperature, and reaction (HTR). To be more specific, the heat that is created inside the cell raises its temperature, which, if it rises over a particular threshold, causes the exothermic processes that are already taking place to go along at a faster rate. The HTR loop is established each time that exothermic activities result in an increase in the total amount of heat emitted. Because of the consistent rise in temperature, there is always the possibility of an accident occurring, such as a fire or an explosion, particularly in the case of large battery packs. It is vital to have an in-depth understanding of the factors and mechanisms that contribute to the thermal runaway of SIBs in order to provide direction for the design of high-safety materials that can be used in dependable and secure batteries. According to the findings of Robinson and colleagues' research, when LIBs and SIBs come into contact with thermal runaway, both types of molecules experience the same chain of events.

1) Pre-stage: The thermal runaway process is always initiated once the temperature of the battery system reaches an unsafe level. The kinetics of the electrochemical reaction, the temperature of the surrounding environment, the amount of heat created during the charge/discharge process, as well as its spatial distribution, are all interdependent on one another in a dynamic way. The particle form of the substance, the porosity of the material, and the distribution of the current density all have a key impact in deciding how it is

dispersed spatially. The rate of heat production at different points inside the cell is inconsistent with one another due to the unequal distribution of current that occurs during cycling.[10-12]

2) Heat accumulation stage:The temperature within the cell is now being fast raised by exothermic chemical chain reactions; the following section goes into further depth on these processes..

Decomposition of SEI:The technique of accelerating rate calorimetry (ARC) was applied to the examination of a Sharp Laboratories of Europe Naion pouch cell that had a capacity of 3000 mA h. This cell was constructed out of layered oxide for the cathode, polypropylene for the separator, hard carbon for the anode, and an electrolyte that conducted sodium ions. The electrolyte was created by combining ethylene carbonate (EC) and diethylene carbonate (DEC) in a mixed solution at a weight ratio of 1:1, along with either 1 mol L⁻¹ (m) of sodium phosphate or lithium phosphate salt. The final product had a weight ratio of 1:1. The SEI layer, which may occur in systems based on either Na or Li, may include a large variety of unique organic and inorganic molecules. This is because the SEI layer can form in either system. These species include polyethylene oxide (PEO), sodium fluoride (NaF), ronalithium, roco3nalithium, and lithium sodium carbonate (Li)₂CO₃.

Anode and electrolyte reactions: When the SEI layer deteriorates, the exposed sodium metal cluster and the injected sodium ions will interact with the electrolyte to reestablish the SEI while simultaneously releasing flammable gases. This process, which is also known as an exothermic reaction, causes an increase in the temperature of the cell.[13-15]

Ionic liquid systems with an intermediate temperature have been reported by Nohira and colleagues as being suitable for use as electrolytes in sodium secondary batteries. These systems are referred to as NaFSA-KFSA and NaTFSACsTFSA, where FSA stands for bis(fluorosulfonyl)amide and TFSA refers for bis(trifluoromethylsulfonyl)amide, which is abbreviated as NTf₂ in this context. Because these electrolytes have broad electrochemical windows, which may reach up to 5.2V when the temperature is 363 kelvin, the researchers came to the conclusion that they might be utilised at working temperatures ranging from 333 to 393 kelvin. These systems provide a number of advantages over Na/S and Na/NiCl₂ batteries, which must be run at a temperature of around 573 kelvin in order to function properly. Their temperature range of operation is far broader. On the other hand, it is optimal for portable energy sources to be able to function properly at room temperature. [16-21]

Wang et al. most recently employed a polymeric gel electrolyte consisting of 1-methyl-3-propylimidazolium iodide and poly (vinylidene fluoride-co-hexafluoropropylene) in order to build a DSSC with an efficiency of 5.3%. This was accomplished by using a polymeric gel electrolyte. For this purpose, an electrolyte consisting of a polymeric gel was utilised. A significant number of researchers were looking at the possibility of renewing dye-sensitized TiO₂ solar cells in the solid state. Conductivity and thermal behaviour of HPA-impregnated PVDF with iodine/iodide-based electrolyte are described in this work in order to assess the viability of employing it in DSSC in order to achieve better levels of efficiency. These researchers developed a novel set of polymer electrolytes to utilise in their investigations. The purpose of this study is to contribute to a better knowledge of the phenomenon of accelerated ionic transport and to get a deeper level of comprehension regarding DSSC.[22-25]

OBJECTIVES OF THE STUDY

1. Research typical thermal runaway in sodium-ion batteries
2. To research sodium battery components that are highly available in nature and have similar insertion mechanisms in electrode materials

RESEARCH METHODOLOGY

[C₄mpyr][NTf₂](99%) was acquired from Merck, whilst Solvionics was responsible for the production of 99.9% of the NaNTf₂ and 98% of the LiNTf₂ in the study. Before being utilised, the compounds did not undergo any additional purification of any kind. [C₄mpyr][NTf₂] was subjected to a Karl Fischer titration, which found that the compound had 125 parts per thousand of water. To begin, 0.1 to 0.5 M worth of various sodium or lithium salt concentrations were added to the ionic liquid. These concentrations ranged from very low to very high. After that, the solutions were mixed vigorously at room temperature in order to ensure that the salts were thoroughly dissolved. After that, any leftover water in the electrolytes was driven off by placing them in a vacuum oven at a temperature of 90 degrees Celsius for two days. In most cases, there was water present at a concentration of 200 parts per million.[26-27]

Characterization

Cyclic voltammetry

The diameter of the working electrodes was one millimetre, and they were made up of nickel and copper electrodes. In the Li electrolytes, the behaviour that was displayed by one of the electrodes was identical to that of the other. On the other hand, a functional Cu electrode produced larger currents when applied to Na electrolytes, which is why we focused on it. Counter and reference electrodes, depending on the electrolyte they were used with, were either constructed of lithium metal for lithium electrolytes or sodium metal for sodium electrolytes. After that, the working electrode was placed on top of an electrolyte drop that had been put upon sodium metal. Despite this, there was no physical connection between the working electrode and the metal at any point. It scanned at a rate of 20 millivolts per second throughout that time. At each and every one of the stages of the therapy method, argon was utilised. Control of the BioLogic SP 200 potentiostat was carried out by means of the EC-LAB software. Using the item, measurements were taken with the temperature kept constant at room temperature.[28-32]

Density and viscosity

For the purpose of determining the density, an Anton Paar DMA 5000 density metre was utilised. The "oscillating U-tube concept" is the method that the density metre employs in order to compute the mass of the liquid that is being measured. In order to conduct the necessary measurements, an Anton PaarAMVn viscosity metre was utilised. This instrument measures viscosity by the falling ball method.[33-36]

Ionic conductivity

The conductivity test was carried out with the use of a locally fabricated dip cell probe, which consisted of two platinum wires wrapped in glass. In order to do the calculation for the cell constant, the temperature was brought up to 25 degrees Celsius, and a solution of 0.01 M KCl was dissolved. For the purpose of determining the ionic conductivity of the synthesised electrolytes, a high frequency response analyzer (HFRA; Solartron 1296) was utilised to collect impedance spectra across a frequency range of 0.1 Hz–10 MHz with an amplitude of 30 mV. This was done in order to quantify the ionic conductivity of the electrolytes. This was done over the whole gamut of frequency ranges. Measurements were taken at 10 different locations at ten-year intervals in each of those locations. The experiment was conducted at temperatures ranging from 273 to 373 degrees Celsius, with 10-degree increments. To keep the temperature at or below one degree Celsius, we made use of a brass block that had a chamber for the cell as well as a cartridge heater that was set up inside of it. Additionally, we utilised a Eurotherm 2204e temperature controller that was attached to the Solartron. In order to evaluate the impedance data and arrive at a conclusion about the conductance, the initial real axis landing point of the Nyquist plot was utilised.[37-39]

Synthesis of precursor

In order to manufacture the formula, aqueous chemical processes were utilised. $\text{NaO}0.493 \text{ B}_2\text{O}_30.087 \text{ SiO}_2\text{SO}_40.190 \cdot n\text{H}_2\text{O}$ was produced by quickly stirring a mixture containing $\text{NaO}_2 \cdot m\text{SiO}_2$ ($m = 3.3$), after which four weight percent H_3BO_3 and ten weight percent Na_2SO_4 were added to the mixture. It was decided to do this in order to forestall the process of devitrification from taking place at room temperature. Continuous stirring was performed on the solution until it took on the appearance of being transparent and clear. After that, the first thing that was done to get things ready was to store the solution in a container that had a lid that could be secured firmly.[40-43]

Electrochemical measurements and thermodynamic process characterization

Using differential scanning calorimetry (DSC) and thermogravimetric (TG) curves at temperatures ranging from 20 to 500 degrees Celsius, the glass transition temperature of the Na_2O , B_2O_3 , and SiO_2 system hydrated glass was determined, and the relationship between it and the optimum working temperature was investigated. The glass transition temperature was found to be higher than the optimum working temperature. This was carried out in order to determine the temperature at which the hydrated glass undergoes the glass transition. The powder was contained within Ampere tubes, the measurement rate was 10 degrees Celsius per minute, an empty Ampere tube served as the reference, and the NETZSCH DSC 200 F3 instrument was the piece of equipment that was used.[44-45]

Each and every electrochemical test was carried out in a range of air temperatures in order to determine the temperature at which the electrolyte functions at its optimum level of effectiveness. In order to generate the CV curves for the voltage window, we made use of a range that extended from 0.0 to 5.0 V. The current would not leap when the voltage got close to the voltage window, which would occur when the electrolyte started to degrade. This would happen when the electrolyte started to break down. Both the resistance value ranges and the electrochemical impedance spectroscopy curves are produced by matching fictional circuits. This is done in order to obtain accurate readings. Conductivity was determined by applying the equation $d/(R \cdot A)$ to the collected data in order to get the answer. In addition, charge-discharge cycle curves for the performance of the cycle were obtained at a rate of 0.01 V s⁻¹ in order to evaluate the performance of the cycle.[46]

DATA ANALYSIS

Voltammetric results

The cyclic voltammograms of 0.4 M sodium and lithium electrolytes may be found displayed in Figure 2. The temperature of the surroundings throughout the taking of these voltammograms was kept constant. On the copper working electrode, a new combination of cathodic and anodic properties is observed each and every time. Anodic currents, on the other hand, indicate that the deposited metals are being dissolved, whilst cathodic currents indicate that sodium or lithium metal is being deposited. On the other hand, lithium begins to deposit at an overpotential of around 0.3V over Li/Li^+ , but sodium begins to deposit at a far lower overpotential of approximately 0.2V compared to Na/Na^+ . The Li voltammetry and the Na voltammetry, taken separately, provided evidence of a high degree of reversibility for both the deposition and the dissolution processes. Earlier research have indicated that this phenomenon has an effect on the Li system. The coulombic efficiency that can be acquired from CVs is often rather poor. This is mostly attributable to the challenges associated with isolating the sodium deposition process during the cathodic scan as well as the unfavourable deposit morphologies that usually manifest themselves throughout the CV experiment. It would appear that both the Li and Na systems in this scenario operate at a level of efficiency equal to thirty percent. Because the lithium process in this IL is known to have an efficiency of greater than 80%, we are now researching on galvanostatic methodologies in order to more accurately quantify the coulombic efficiency

of the sodium deposition/dissolution process. In addition to that, one of our goals right now is to include this electrolyte into a sodium battery.[47]

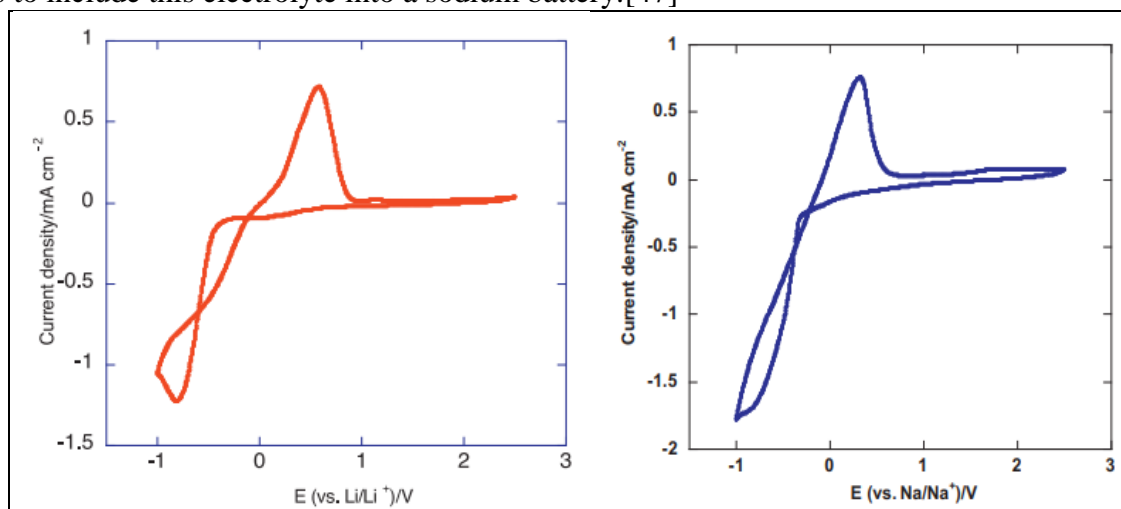


Fig. 1. The following concentrations of NTf2 ions were used for the cyclic voltammograms performed on C4mpyrNTf2-based electrolytes: 0.4 M LiNTf2 (on top) and 0.4 M NaNTf2 (on bottom) equal 20 mVs⁻¹.

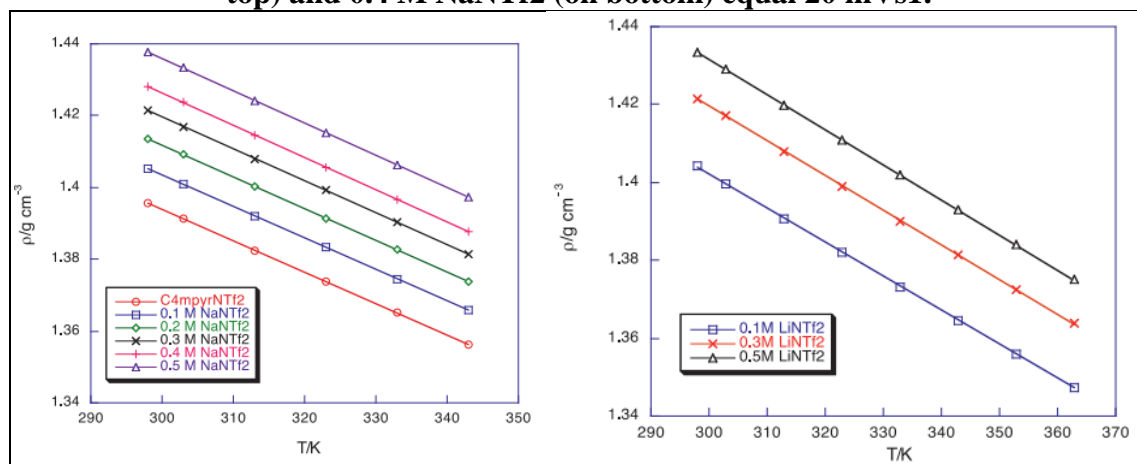


Fig. 2. The density of C4mpyrNTf2-based electrolytes at various sodium NTf2 and lithium NTf2 concentrations.

Density

Both lithium and sodium are examples of electrolytes that see a rise in their densities in response to an increase in the quantity of added salt. Figure 2 depicts how a linear relationship existed between the temperature and the change in density of both electrolytes. The linear temperature dependence was validated over the whole temperature spectrum that was analysed by fitting the data to Equation (1), which resulted in correlation coefficients that were more than or equal to 0.999. This was accomplished across the board. Table 2 provides a representation of the fitting parameters for your perusal. It should come as no surprise that electrolytes that include sodium have a density that is noticeably greater than that of lithium-containing electrolytes. This is due to the fact that the mass of the sodium cation is greater than the mass of the lithium cation.[48]

$$\rho = a + bT \dots\dots\dots(\text{Eq. 1})$$

Table 1 Parameters for a linear fit based on C4mpyrNTf2 for the temperature-dependent density of sodium-containing electrolytes.

Sample	a (g cm ⁻³)	b (g cm ⁻³ K ⁻¹)	R ²
0.5 M NaNTF ₂	1.7051	8.9768E-4	1.000

0.4 M NaNTf ₂	1.6954	8.9751E-4	0.998
0.3 M NaNTf ₂	1.6864	8.8955E-4	0.998
0.2 M NaNTf ₂	1.6764	8.8225E-4	1.000
0.1 M NaNTf ₂	1.6671	8.7905E-4	0.998
C4mpyrNTf ₂	1.6568	8.7574E-4	0.998

Viscosity and ionic conductivity

Arrhenius graphs illustrating the viscosity of several electrolytes, including lithium and sodium, are presented in Figure 3. It is believed that the addition of alkali salts causes an increase in viscosity because of the interaction of metal ions with the NTf₂ anion. In the case of Na⁺, the cation that is being added, the outcome of this interaction is the formation of ion pairs or clusters that are of a greater size and greater mass. The temperature dependency may be well described by the Vogel-Tamman-Fulcher (VTF) equation, which can be found in Eq. (2).

$$\eta = \eta_0 \exp \left[\frac{B}{T - T_0} \right] \dots \dots \dots (Eq. 2)$$

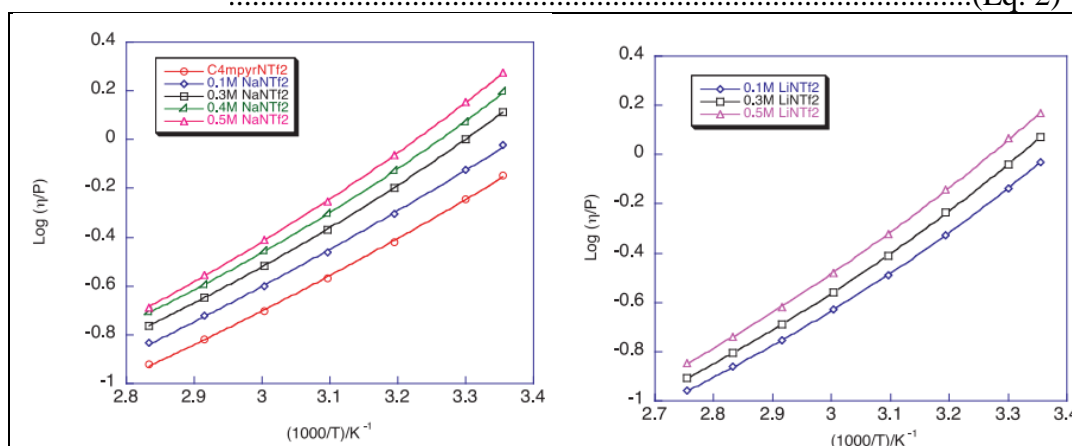


Fig. 3. NaNTf₂ and LiNTf₂ are the top and bottom C4mpyrNTf₂-based electrolytes in Arrhenius graphs illustrating the viscosity of electrolytes, respectively..

Table 3 presents the parameters that were derived from the data and used to adjust the VTF equation to better suit the data. As was forecasted, the viscosity will lessen as the temperature continues to climb. The amount of energy necessary for ion mobility in the ionic liquid is correlated with the pseudo oactivation energy, which is sometimes referred to as the B parameter. This energy seems to continually increase as the salt concentration increases. This leads one to believe that the viscosity will increase upon the addition of Li/Na salt, and that a greater amount of energy will be required for the transport of ions in mixed systems that are more viscous. The increased viscosity of the material is the root cause of this issue. Additionally, it has been determined that electrolytes that contain lithium typically have B values that are a little bit lower than electrolytes that contain sodium. This is the case the majority of the time. The Arrhenius plots that demonstrate the ionic conductivity of each of these electrolytes are displayed in Figure 4.[49]

Table 2Parameters of VTF viscosity for lithium- and sodium-containing C4mpyrNTf₂-based electrolytes.

Sample	Log 0 (P) NaNTf ₂	B (K) NaNTf ₂	T0 (K) NaNTf ₂	Log 0 (P) LiNTf ₂	B (K) LiNTf ₂	T0 (K) LiNTf ₂
0.5 M	-2.8 ± 0.06	377 ± 21	176 ± 3	-2.9 ± 0.11	294 ± 38	169 ± 6
0.3 M	-2.6 ± 0.02	325 ± 9	183 ± 4	-2.7 ± 0.00	330 ± 2	179 ± 0.2

0.1 M	-2.7 ± 0.03	352 ± 7	168 ± 1	-2.6 ± 0.02	197 ± 3	183 ± 0.4
C ₄ mpyrNTf ₂	-2.6 ± 0.01	299 ± 4	177 ± 1	-2.6 ± 0.1	299 ± 6	177 ± 1

Composition adjustment

Table 3 illustrates the typical connections that can be made between composition and conductivity. The quantities of sodium silicate, NaO₂•mSiO_m, hydrogen peroxide, and sodium hydroxide are all connected to one another. In order to simplify and make it more understandable, we re-drew it as figure 6. Before being examined at a temperature of 80 degrees, each sample goes through an acceptable drying process at 60 degrees. To begin, we may deduce from the green triangles that an extremely low concentration of Na⁺ is necessary to achieve the desired improvement in conductivity. This is done in order to facilitate the transfer of ions at a faster rate. The role that Na₂O plays in the system is that of a network modifier; the more Na⁺ that is supplied, the more intervals that are formed in the network. As a direct consequence of this, the occurrence of this phenomenon took place. The process of devitrification starts far before the concentration of Na₂SO₄ in the solution reaches 15% by weight. This is because of the extraordinarily low amount of solution solubility that Na₂SO₄ has. When SO₂ 4 is added to the network, the presence of large anions will likewise cause the route to become blocked. As a consequence of this, the enhancement will only be as beneficial as the quantity of Na₂SO₄ that is applied. Second, as can be seen by the black squares, the conductivity has a link with the value of m that is antithetical to itself. This occurs as a result of the fact that when the value of m increases, there is a corresponding decrease in the amount of Na⁺ that is present. What has to be shown is how insufficient structural stability prevents conductivity from growing while m continues to decrease. The purpose of the red circles on the graph is to emphasise how little of an impact the H₃BO₃ concentration has on the mechanical characteristic and how much more obviously it helps to enhance it. If H₃BO₃ is not supplied to the system, the electrolyte will break down very quickly during the heat treatment and the packing process. More critically, it will break down while it is being used. This is because H₃BO₃ has the power to prevent the electrolyte from breaking up into smaller pieces.[50]

Table 3. Conductivities of samples with various concentrations of sodium silicate (NaO₂•mSiO₂), boron trioxide (H₃BO₃), and sodium sulphate (Na₂SO₄).

w(Na ₂ SO ₄) (%)	σ (S cm ⁻¹)	m	σ (S cm ⁻¹)	w(H ₃ BO ₃) (%)	σ (S cm ⁻¹)
15	6.554 × 10 ⁻³				
10	5.424 × 10 ⁻³	4.2	2.375 × 10 ⁻³	4	4.691 × 10 ⁻³
5	3.608 × 10 ⁻³	3.1	5.424 × 10 ⁻³	2	5.424 × 10 ⁻³
0	1.114 × 10 ⁻³	2.2	7.530 × 10 ⁻³		6.362 × 10 ⁻³

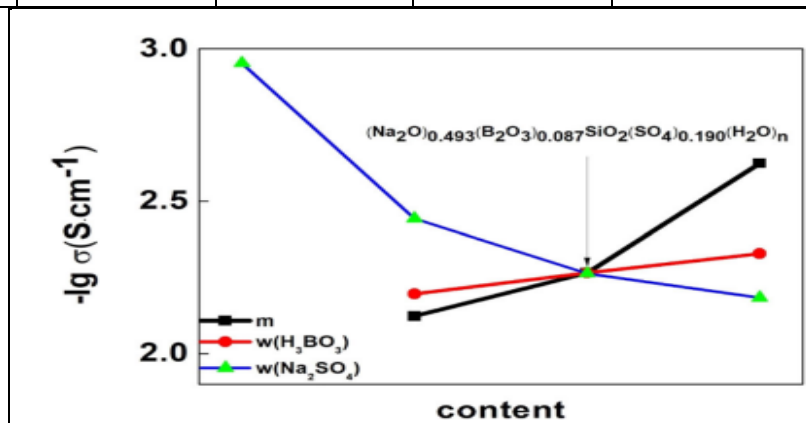


Figure 4. Sample conductivities expressed as NaO₂•mSiO₂ for samples with varying amounts of sodium sulphate, boron trioxide, and sodium silicate.[51-52]

CONCLUSION

We investigated the densities, viscosities, conductivities, thermal properties, and electrochemical parameters of electrolytes formed of C4mpyrNTf₂ that included sodium ions. The concentrations of T_{cr} and T_m decreased, however the concentration of the electrolyte T_g increased, as a result of an increase in the quantity of sodium salt that was provided. Conductivities and viscosities were satisfactorily described by the equations derived from VTF data. The dependence of the sodium ion concentration may be inferred from the lower conductivities and the greater viscosities, respectively. It is possible to accurately characterise any system by using the Walden Rule in fractional form. $\gamma = 0.87 \pm 0.02$. The sodium metal initially starts to deposit at a voltage of around 0.2 volts, and once deposits have formed, they have the capacity to be successfully oxidised back into the electrolyte. Redox reactions are the term used to describe this kind of response. We conclude that C4mpyrNTf₂-based sodium-containing electrolytes are attractive as electrolytes for secondary sodium batteries. This is because sodium-based electrolytes based on C4mpyrNTf₂ may be able to avoid the expenses and environmental problems related to conventional electrolytes while yet exhibiting high conductivities and stabilities. We thus conclude that sodium-based electrolytes based on C4mpyrNTf₂ are potential candidates for the electrolyte of secondary sodium batteries. A sort of quasi-solid sodium ion electrolyte was created using an aqueous chemical method and the Na₂OBO₃SiO₂H₂O hydrated glass system. Sodium ions were used to generate this electrolyte. This electrolyte had sodium ions in its structure. The solid electrolyte will change into a state that is more akin to a quasi-solid when the temperature at which the glass transition occurs is exceeded. This condition has a constant mechanical and cyclic performance, a conductivity of 5.425 10³ S cm⁻¹, and a voltage window of 2.24 V. It also combines the advantages that gel and ceramic electrolytes have to offer. We are able to operate the system in a broad variety of temperatures since the T_g of the system may be changed from 10 to 150 degrees Celsius. We may utilise it specifically anywhere between -40 and +40 degrees Celsius. it is liquid phase The ability of hydrated system glass, which is made of Na₂OBO₃SiO₂H₂O, to fuse with the electrodes during processing offers the twin benefits of reducing interface resistance and boosting battery stability. This is because the contact between the glassy solid electrode and the electrolyte has an impact on how the battery behaves. This interaction heavily relies on the electrolyte. In practically every part of the world, natural resources may be found in big numbers and at little cost. The procedure is simple, eco-friendly, and opens up some intriguing options for the electrolyte's potential future use.

REFERENCES

- [1] A. Andriola, K. Singh, J. Lewis, L. Yu, Conductivity, viscosity, and dissolution enthalpy of Lintf₂ in ionic liquid Bmintf₂, J. Phys. Chem. B 114 (2010) 11709–11714.
- [2] B.L. Ellis, L.F. Nazar, Sodium and sodium-ion energy storage batteries, Curr. Opin. Solid State Mater. Sci. 16 (2012) 168–177.
- [3] J.A. Choi, E.G. Shim, B. Scrosati, D.W. Kim, Mixed electrolytes of organic solvents and ionic liquid for rechargeable lithium-ion batteries, Bull. Korean Chem. Soc. 31 (2010) 3190–3194.
- [4] G.H. Lane, P.M. Bayley, B.R. Clare, A.S. Best, D.R. MacFarlane, M. Forsyth, A.F. Hollenkamp, Ionic liquid electrolyte for lithium metal batteries: physical, electrochemical, and interfacial studies of N-Methyl-

- NButylmorpholiniumBis(Fluorosulfonyl)Imide, *J. Phys. Chem. C* 114 (2010) 21775–21785.
- [5] J.S. Lee, N.D. Quan, J.M. Hwang, J.Y. Bae, H. Kim, B.W. Cho, H.S. Kim, H. Lee, Ionic liquids containing an ester group as potential electrolytes, *Electrochem. Commun.* 8 (2006) 460–464.
- [6] D.Q. Nguyen, J.h. Oh, C.S. Kim, S.W. Kim, H. Kim, H. Lee, H.S. Kim, Synthesis and characterization of quaternary ammonium-based ionic liquids containing Al Alkyl carbonate group, *Bull. Korean Chem. Soc.* 28 (2007) 2299–2302.
- [7] R.M. Dell, Batteries - fifty years of materials development, *Solid State Ionics* 134 (2000) 139–158.
- [8] M. Egashira, T. Asai, N. Yoshimoto, M. Morita, Ionic conductivity of ternary electrolyte containing sodium salt and ionic liquid, *Electrochim. Acta* 58 (2011) 95–98.
- [9] D. Kumar, S.A. Hashmi, Ion transport and ion-filler-polymer interaction in Poly(Methyl Methacrylate)-based, sodium ion conducting, gel polymer electrolytes dispersed with silica nanoparticles, *J. Power Sources* 195 (2010) 5101–5108.
- [10] T. Nohira, T. Ishibashi, R. Hagiwara, Properties of an intermediate temperature ionic liquid NaTFSA-CsTFSA and charge- discharge properties of NaCrO₂ positive electrode at 423K for a sodium secondary battery, *J. Power Sources* 205 (2012) 506–509.
- [11] J.L. Sudworth, The sodium/sulphur battery, *J. Power Sources* 11 (1984) 143–154. J. Coetzer, A new high energy density battery system, *J. Power Sources* 18 (1986) 377–380.
- [12] A. Fukunaga, T. Nohira, Y. Kozawa, R. Hagiwara, S. Sakai, K. Nitta, S. Inazawa, Intermediate-temperature ionic liquid Nafsa-Kfsa and its application to sodium secondary batteries, *J. Power Sources* 209 (2012) 52–56.
- [13] C.-L. Yu, J. Winnick, P. Kohl, Novel electrolyte for the sodium/iron chloride battery, *J. Electrochem. Soc.* 138 (1991) 339–340.
- [14] C. Scordilis-Kelley, J. Fuller, R. Carlin, J. Wilkes, Alkali metal reduction potentials measured in chloroaluminate ambient-temperature molten salts, *J. Electrochem. Soc.* 139 (1992) 694–699.
- [15] A. Andriola, K. Singh, J. Lewis, L. Yu, Conductivity, viscosity, and dissolution enthalpy of LiTf₂ in ionic liquid Bmintf₂, *J. Phys. Chem. B* 114 (2010) 11709–11714.
- [16] B.L. Ellis, L.F. Nazar, Sodium and sodium-ion energy storage batteries, *Curr. Opin. Solid State Mater. Sci.* 16 (2012) 168–177.
- [17] J.A. Choi, E.G. Shim, B. Scrosati, D.W. Kim, Mixed electrolytes of organic solvents and ionic liquid for rechargeable lithium-ion batteries, *Bull. Korean Chem. Soc.* 31 (2010) 3190–3194.
- [18] G.H. Lane, P.M. Bayley, B.R. Clare, A.S. Best, D.R. MacFarlane, M. Forsyth, A.F. Hollenkamp, Ionic liquid electrolyte for lithium metal batteries: physical, electrochemical, and interfacial studies of N-Methyl-NButylmorpholiniumBis(Fluorosulfonyl)Imide, *J. Phys. Chem. C* 114 (2010) 21775–21785.
- [19] J.S. Lee, N.D. Quan, J.M. Hwang, J.Y. Bae, H. Kim, B.W. Cho, H.S. Kim, H. Lee, Ionic liquids containing an ester group as potential electrolytes, *Electrochem. Commun.* 8 (2006) 460–464.
- [20] D.Q. Nguyen, J.h. Oh, C.S. Kim, S.W. Kim, H. Kim, H. Lee, H.S. Kim, Synthesis and characterization of quaternary ammonium-based ionic liquids containing Al Alkyl carbonate group, *Bull. Korean Chem. Soc.* 28 (2007) 2299–2302.

- [21] R.M. Dell, Batteries - fifty years of materials development, *Solid State Ionics* 134 (2000) 139–158.
- [22] M. Egashira, T. Asai, N. Yoshimoto, M. Morita, Ionic conductivity of ternary electrolyte containing sodium salt and ionic liquid, *Electrochim. Acta* 58 (2011) 95–98.
- [23] D. Kumar, S.A. Hashmi, Ion transport and ion-filler-polymer interaction in Poly(Methyl Methacrylate)-based, sodium ion conducting, gel polymer electrolytes dispersed with silica nanoparticles, *J. Power Sources* 195 (2010) 5101–5108.
- [24] T. Nohira, T. Ishibashi, R. Hagiwara, Properties of an intermediate temperature ionic liquid NaTFSA-CsTFSA and charge- discharge properties of NaCrO₂ positive electrode at 423K for a sodium secondary battery, *J. Power Sources* 205 (2012) 506–509.
- [25] J.L. Sudworth, The sodium/sulphur battery, *J. Power Sources* 11 (1984) 143–154.
- [26] J. Coetzer, A new high energy density battery system, *J. Power Sources* 18 (1986) 377–380.
- [27] A. Fukunaga, T. Nohira, Y. Kozawa, R. Hagiwara, S. Sakai, K. Nitta, S. Inazawa, Intermediate-temperature ionic liquid NaFSA-KFSA and its application to sodium secondary batteries, *J. Power Sources* 209 (2012) 52–56.
- [28] C.-L. Yu, J. Winnick, P. Kohl, Novel electrolyte for the sodium/iron chloride battery, *J. Electrochem. Soc.* 138 (1991) 339–340.
- [29] C. Scordilis-Kelley, J. Fuller, R. Carlin, J. Wilkes, Alkali metal reduction potentials measured in chloroaluminate ambient-temperature molten salts, *J. Electrochem. Soc.* 139 (1992) 694–699.
- [30] Fuller TF, Doyle M, Newman J. Simulation and Optimization of the Dual Lithium Ion Insertion Cell. *Journal of The Electrochemical Society.* 1994;141(1):1-10.
- [31] Doyle M, Newman J, Gozdz AS, Schmutz CN, Tarascon JM. Comparison of Modeling Predictions with Experimental Data from Plastic Lithium Ion Cells. *Journal of The Electrochemical Society.* 1996;143(6):1890-903.
- [32] Sankarasubramanian S, Krishnamurthy B. A capacity fade model for lithium-ion batteries including diffusion and kinetics. *Electrochimica Acta.* 2012;70:248-54.
- [33] Guo M, White RE, J. Power Sources. A distributed thermal model for a Li-ion electrode plate pair. *Journal of Power Sources.* 2013;221:334-44.
- [34] Guo G, Long B, Cheng B, Zhou S, Xu P, Cao B. Three-dimensional thermal finite element modeling of lithium-ion battery in thermal abuse application. *Journal of Power Sources.* 2010;195(8):2393-8.
- [35] Yang S, Wang X, Yang X, Bai Y, Liu Z, Shu H, et al. Determination of the chemical diffusion coefficient of lithium ions in spherical Li[Ni_{0.5}Mn_{0.3}Co_{0.2}]O₂. *Electrochimica Acta.* 2012;66:88-93.
- [36] Jiang F, Peng P. Elucidating the Performance Limitations of Lithium-ion Batteries due to Species and Charge Transport through Five Characteristic Parameters. *Scientific Reports.* 2016;6:32639.
- [37] Huang J, Li Z, Liaw BY, Wang Z, Song S, Wu N, et al. Entropy Coefficient of a Blended Electrode in a Lithium-Ion Cell. *Journal of The Electrochemical Society.* 2015;162(12):A2367-A71.
- [38] M. Watanabe, N. Ogata, J.R. MacCallum, C.A. Vincent (Eds.); *ëPolymer Electrolyte Reviews-11*, Elsevier, New York, 42 (1987).
- [39] J.Y. Song, Y.Y. Wang, C.C. Wan; *J. Electrochem. Soc.*, 147, 3219 (2000).
- [40] G.B. Appetecchi, F. Croce, A. DePaolis, B. Scrosati; *J. Electroanal. Chem.*, 463, 248 (1999).
- [41] J.L. Souquet, M. Duclot, M. Levy; *Solid State Ionics*, 85, 149 (1996).

- [42] D.R.Lide; *Hand book of Chemistry and Physics*, CRC Press, Boca Raton, Florida (1990).
- [43] L.Greenspan; *J.Res.Natl.Inst.Stand.*, 81A, 89 (1976).
- [44] C.Trolliet, G.Coudurier, J.C.Vedrine; *Topics in Catalysis.*, 15, 73 (2001).
- [45] K.Pamin, A.Kubacka, Z.Olejniczak, J.Haber, B.Sulikowski; *Appl.Catal.A.Gen.*, 194-195, 137 (2000).
- [46] E.Adem, J.Rickards, E.Munoz, G.Burillo, L.Cota, M.Avalos-Norja; *Rev.Mex.Fis.*, 49, 37 (2003)
- [47] Z. Zhang, Q. Zhang, C. Ren, F. Luo, Q. Ma, Y.-S. Hu, Z. Zhou, H. Li, X. Huang, L. Chen, A ceramic/polymer composite solid electrolyte for sodium batteries, *J. Mater. Chem.* 4 (2016) 15823–15828.
- [48] Y.L. Ni'mah, M.-Y. Cheng, J.H. Cheng, J. Rick, B.-J. Hwang, Solid-state polymer nanocomposite electrolyte of TiO₂/PEO/NaClO₄ for sodium ion batteries, *J. Power Sources* 278 (2015) 375–381.
- [49] C.V.S. Rao, M. Ravi, V. Raja, P.B. Bhargav, A.K. Sharma, V.N. Rao, Preparation and characterization of PVP-based polymer electrolytes for solid-state battery applications. *Iran, Polym. J.* 21 (2012) 531–536.
- [50] A.M. Stephan, S.G. Kumar, N. Renganathan, M.A. Kulandainathan, Characterization of poly(vinylidene fluoride-hexafluoropropylene)(PVdF-HFP) electrolytes complexed with different lithium salts, *Eur. Polym. J.* 41 (2005) 15–21.
- [51] Z. Zhang, K. Xu, X. Rong, Y.-S. Hu, H. Li, X. Huang, L. Chen, Na_{3.4}Zr_{1.8}Mg_{0.2}Si₂PO₁₂filled poly (ethylene oxide)/Na(CF₃SO₂)₂Naflexible composite polymer electrolyte for solid-state sodium batteries, *J. Power Sources* 372 (2017) 270–275.
- [52] B. Zhang, R. Tan, L. Yang, J. Zheng, K. Zhang, S. Mo, Z. Lin, F. Pan, Mechanisms and properties of ion-transport in inorganic solid electrolytes, *Energy Storage Materials* 10 (2018) 139–159.