



Molten salt electrolyte based high-temperature calcium metal batteries?

Downloaded from: <https://research.chalmers.se>, 2026-10-13 03:06 UTC

Citation for the original published paper (version of record):

Timhagen, J., Ponrouch, A., Weidow, J. et al (2026). Molten salt electrolyte based high-temperature calcium metal batteries?. *Electrochemistry Communications*, 186.
<http://dx.doi.org/10.1016/j.elecom.2026.108154>

N.B. When citing this work, cite the original published paper.



Molten salt electrolyte based high-temperature calcium metal batteries?

Johanna Timhagen^a, Alexandre Ponrouch^{b,c}, Jonathan Weidow^a, Patrik Johansson^{a,c,d,*}

^a Department of Physics, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden

^b Institut de Ciència de Materials de Barcelona (ICMAB-CSIC) Campus UAB, E-08193 Bellaterra, Catalonia, Spain

^c ALISTORE-European Research Institute, CNRS, FR 3104, Hub de l'Energie, 80039 Amiens, France

^d Department of Chemistry – Ångström, Uppsala University, 751 21 Uppsala, Sweden

ARTICLE INFO

Keywords:

Eutectic electrolytes
Calcium batteries
Multivalent batteries
High-temperature batteries
Multi-cationic electrolytes

ABSTRACT

Clever electrolyte design is crucial for any next generation battery (NGB) technology in its infancy to enable leapfrogging. Using molten salt electrolytes (MSEs) in calcium metal batteries (CMBs) opens possibilities in terms of safety, abundance, and high-temperature applications. Herein, equimolar compositions of $\text{Ca}(\text{FSI})_2$ together with the analogous Li- , Na- , and KFSI salts are combined in three ternary and one unique quaternary MSE, for which the mechanisms and limiting processes of metal plating and stripping in symmetric $\text{Ca}||\text{Ca}$ cells are evaluated, using both a classic set-up and a method inspired by symmetric cathode tests. While Ca metal anodes still face issues with passivation layers, using MSEs can be feasible under the right conditions, and the combination represents a small steppingstone towards practical high-temperature CMBs.

1. Introduction

As global energy consumption increases [1], the demand for energy storage and more performant batteries has risen [2]. This has led to the search for post-lithium-ion batteries to achieve higher energy densities [3], longer cycle lives [4], and the use of more abundant raw materials [5,6], among other objectives. In particular, next generation batteries (NGBs) based on metal anodes promise far higher energy densities than their intercalation anode counterparts [7]. Also, batteries operational both far below and far above ambient temperature are gaining interest [8]. Elevated temperature capability is of interest to simplify the design of appliances that generate significant internal heat during operation, thus requiring cooling systems to keep control and safety, such as in electric vehicles (EVs) and grid energy storage, but in particular those naturally operating at high temperature in more extreme environments, such as in desert climates and for space exploration [8,9].

Combining metal anode cell designs with high-temperature operation demands careful consideration – which *a priori* can, as a first level of approximation, be based on basic physico-chemical and electrochemical properties. In brief, lithium offers both the lowest electrochemical potential and an acceptable melting temperature of 180 °C, but has a critically low abundance [6]. Potassium and sodium, both much more abundant elements, have sufficiently low electrochemical potentials, but very low melting temperatures (64 and 98 °C, respectively), making any

high-temperature operation a safety challenge. Other metals proposed for battery application, such as magnesium, aluminum, and zinc, have adequate melting points (>419 °C), but less appealing electrochemical potentials, hindering high energy density cells to be designed. Calcium, on the other hand, combines an electrochemical potential close to that of lithium (within ca. 0.1–0.2 V), a very large abundance (41,500 ppm, 5th among elements in the Earth's crust) [10], with a high melting temperature (842 °C) and very high, both, gravimetric (1340 mAh g⁻¹) and volumetric (2060 mAh cm⁻³) capacities [11] – hence appealing as a first level approximation.

Calcium metal batteries (CMBs) operating at elevated/high temperatures are not a new concept; the first proof of acceptably reversible calcium plating and stripping was performed at 75 and 100 °C, using a standard liquid electrolyte of $\text{Ca}(\text{BF}_4)_2$ in EC:PC [12], which in fact caused the very revival of CMB R&D. Not long after, plating and stripping were, however, also achieved at room temperature [13], swiftly shifting the focus of the community. Both the Ca metal anode propensity towards passivation layers [14], and any high-temperature compatible electrolytes requirement of high thermal stability and low vapor pressures [8], renders clever electrolyte design to be of utmost importance for practical CMBs. Solvent-free electrolytes, such as ceramic solid-state electrolytes (SSEs) and (semi-solid) molten salt electrolytes (MSEs), are attractive alternatives for high-temperature CMBs, as there is no risk of solvent degradation nor ignition/flammability or vapor pressure build-

* Corresponding author at: Department of Physics, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden.

E-mail address: patrik.johansson@kemi.uu.se (P. Johansson).

<https://doi.org/10.1016/j.elecom.2026.108154>

Received 6 February 2026; Received in revised form 23 March 2026; Accepted 24 March 2026

Available online 28 March 2026

1388-2481/© 2026 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

up, as there are no organic components in their compositions, hence fundamentally greater safety. However, SSEs, especially due to their significant volume changes during cycling, often experience poor electrode contact, and their strong electrostatic interactions with multivalent cations cause low ionic conductivities and slow dynamics [15]. In comparison, MSEs also suffer from low ionic conductivities, due to their high viscosities, which is further complicated by poorly understood ionic transport mechanisms [16,17]. However, MSEs do provide good electrode contact and typically exhibit wide electrochemical windows, which open opportunities for high-voltage applications [18,19].

Combining the above, we here target high-temperature CMBs, employing several ternary and a quaternary MSEs based on calcium bis (fluorosulfonyl)imide ($\text{Ca}(\text{FSI})_2$) in combination with analogous Li-, Na-, and KFSI salts in equimolar compositions – whose physico-chemical properties in relation to their entropy of mixing (ΔS_{mix}), which some of us previously have reported on [20]. By using an operating temperature of 100 °C, ~ 25–50 °C higher than their initial melting temperatures (T_m) (Table 1), issues of high viscosities and consequently low ionic conductivities are at least partly avoided [21]. This allows us to test the MSEs for high-temperature CMB designs in both classic and more elaborate symmetric $\text{Ca}||\text{Ca}$ cells, and to start elucidating their promises and problems from a mechanisms-and-limiting-processes perspective of metal plating and stripping.

2. Experimental details

2.1. MSE preparation

Four commercial salts were used to prepare the MSEs: $\text{Ca}(\text{FSI})_2$ (Provisco CS, 99.0%), LiFSI (Nippon Shokubai Co., Ltd., 99.9%), NaFSI (Solvionic, 99.7%) and KFSI (Nippon Shokubai Co., Ltd., 99%), where the former was used as received, and all other salts were dried in a Büchi vacuum oven (<7 Pa and 72 h at 80 °C). The four equimolar composed MSEs, henceforth denoted: Ca-Li-Na-K, Ca-Li-Na, Ca-Li-K, and Ca-Na-K, were all prepared by mixing the ingoing salts and grinding them together manually with a mortar and pestle for ~15 min inside an Ar-filled glovebox (H_2O < 1 ppm, O_2 < 1 ppm).

2.2. Electrochemical testing

For initial testing, symmetric $\text{Ca}||\text{Ca}$ 2-electrode Swagelok cells, design A, were assembled inside an Ar-filled glovebox (H_2O < 1 ppm, O_2 < 1 ppm) using MSEs in powder form, glass microfiber separators (Whatman® paper), and pressed Ca metal granules (Alfa Aesar, 99.5%), which were scraped with a stainless-steel spatula just before assembly. The cells were stacked as follows: Ca metal, ~40 mg of MSE, separator, ~40 mg of MSE, separator, ~40 mg of MSE, and Ca metal. The cells were held at open-circuit voltage (OCV) for 3 h in an oven at 100 °C, then galvanostatically cycled at a current density of 0.02 mA/cm² with a cut-off voltage of ±2.5 V until failure.

Subsequent coin cell tests used a Ca metal foil (ACI Alloys, 99.5% purity, 0.25 mm thickness), which was polished using a Dremel® 8260 rotary tool equipped with a silicon carbide (SiC) tip and further scraped with a stainless-steel spatula right before assembly. These cells, design B, were stacked as follows: Ca metal, ~50 mg of MSE, separator, ~50 mg of MSE, and Ca metal. The cells were heated on a hotplate at 100 °C to melt the MSE before crimping. Cells were held at OCV for 3 h in an oven

at the chosen temperature (60, 80, or 100 °C), then a current density of 0.05 mA/cm² was applied until –3.5 V was reached; thereafter, galvanostatically cycled at 0.02 mA/cm², with a cut-off voltage of ±2 V, until failure.

The split coin cells (design C, see below) used the same cycling protocol (3 h in an oven at 100 °C followed by a current density of 0.05 mA/cm² until –3.5 V was reached), whereafter, while they were still hot, the cells were disassembled, and the separators carefully removed. The oxidized (and *vice-versa* the reduced) electrodes were paired and assembled in new cells stacked as follows: electrode, ~50 mg of new MSE, new separator, ~50 mg of new MSE, and electrode. Once again, the cells were heated on a hotplate at 100 °C to melt the MSE before crimping and held at OCV for 3 h in an oven at 100 °C, then galvanostatically cycled at a current density of 0.02 mA/cm², with a cut-off voltage of ±2 V, until failure.

3. Results and discussion

First, all MSEs were electrochemically tested according to cell designs A and B, to explore possible effects of $T_m/\Delta S_{\text{mix}}$ and charge density differences. Then, solely the Ca-Na-K MSE was used in design C cells, to investigate mechanisms and limiting processes in more detail.

The three ternary and the quaternary MSEs were all cycled at 100 °C (Fig. 1a) – an operation temperature that renders all MSEs enough internal dynamics to allow for symmetric $\text{Ca}||\text{Ca}$ Swagelok cells cycling, *i. e.*, design A. While MSEs in principle should allow for operation >100 °C, other cell components have challenges at these temperatures, why we have refrained from tests above 100 °C. The Ca-Li-Na MSE based cell, thus employing the MSE with the highest T_m , only lasts <3 cycles, but for the other cells/MSEs, there is no such correlation discernible: the MSE with the lowest T_m – the quaternary Ca-Li-Na-K – does not result in the cell that cycles the best. Instead, the Ca-Li-Na-K MSE based cell shows virtually no difference to the Ca-Li-K MSE based cell, indicating that, while adding NaFSI increases the ΔS_{mix} [20] and decreases the T_m (Table 1), it has no beneficial effect on the cyclability. In contrast, the cell/MSE without any LiFSI, Ca-Na-K, achieves the most cycles. Still, the voltage hysteresis is high for all cells/MSEs, and to get comparable results, the cut-off voltage had to be set to ±2.5 V.

Looking more closely at the 2nd cycle (Fig. 1b), there is an initial small overpotential peak for the Ca-Na-K MSE upon oxidation, most likely due to the nucleation overpotential on the counter-electrode. With the continuation of stripping, the voltage hysteresis slightly decreases reaching a pseudo-plateau at ca. 200 mV which length depends on the MSE and being the longest for Ca-Na-K. Afterwards the voltage hysteresis increases to reach another pseudo-plateau at ca. 1.7 V. Our working hypothesis is to attribute the first pseudo-plateau to the initial stripping of the fresh deposit, followed by stripping of bulk calcium. Notably, the quaternary MSE based cell exhibits high voltage hysteresis from the very start. While these multi-cationic MSEs open up the possibility of plating several metals, not just Ca, and they indeed have similar reduction potentials in water, the same is not necessarily true for solvent-free electrolytes. Additionally, the low melting temperatures of the alkali metals involved mean they cannot be expected to plate in the same way as Ca does. To further analyze the origins of the voltage hysteresis, a series of tests using design B cells at different current densities were made (Fig. S1) and indeed achieved a lower voltage hysteresis of 60–140 mV, depending on MSE, lasting the full-half cycle but only for the oxidation part (Fig. 2). Despite this, the same trend as for design A is obtained; the Ca-Na-K MSE based cell has the lowest voltage hysteresis upon oxidation the longest, while the cells based on the Ca-Li-Na-K and Ca-Li-K MSEs perform more or less equally, and the Ca-Li-Na MSE based cell the worst.

Previously, using the lowered T_m , but foremost the entropic stabilization of MSEs as the variable/measure, the quaternary Ca-Li-Na-K MSE showed the best long-term stability/preservation of local structure [20]. Here, cyclability does not seem to be affected the same way by the increased ΔS_{mix} or lower T_m . The latter was further challenged by cycling

Table 1
Initial melting and glass transition temperatures of the four MSEs tested [20].

MSE	T_m (°C)	T_g (°C)
Ca-Li-Na-K	54	–14
Ca-Li-Na	75	–13
Ca-Li-K	68	–19
Ca-Na-K	61	–11

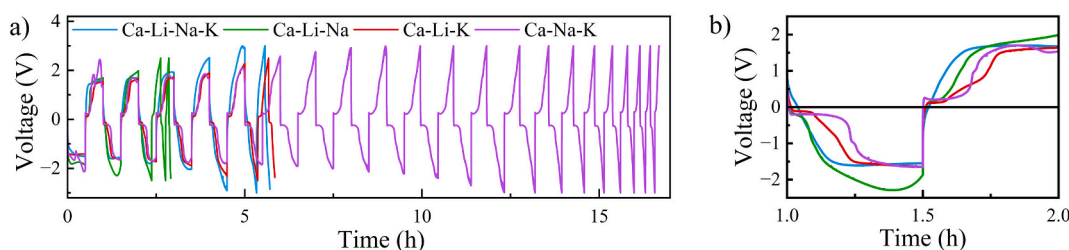


Fig. 1. Symmetric Ca||Ca cells, design A, cycled at 100 °C: a) full cycling and b) 2nd cycle.

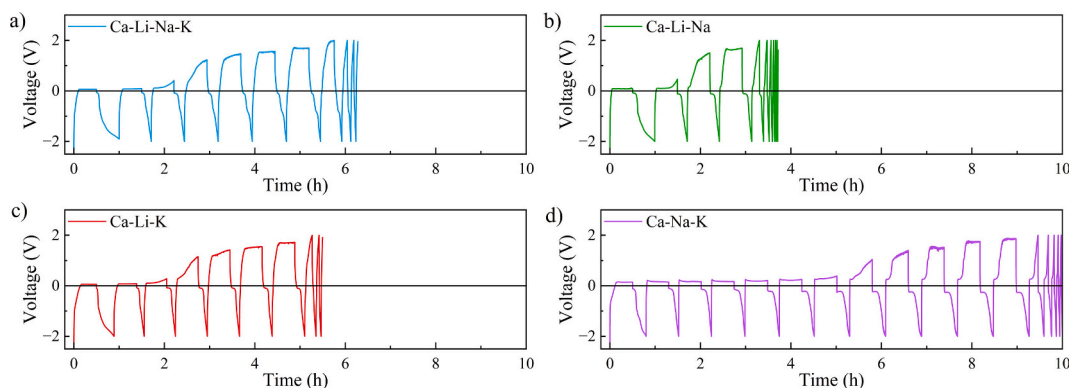


Fig. 2. Symmetric Ca||Ca coin cells, design B, cycled at 100 °C: a) Ca-Li-Na-K, b) Ca-Li-Na, c) Ca-Li-K, and d) Ca-Na-K.

at 80 and even 60 °C (Fig. 3), which is lower than the initial T_m of some of the MSEs (Table 1). However, these initial T_m only result from the first heating of the crystalline powder mixtures, which, after melting form MSEs which in the second heating cycle only display T_g , thus best seen as semi-solids and suggested to allow for cycling. Both the cells based on the Ca-Li-Na-K and the Ca-Li-Na MSEs performed worse at 80 °C, as expected, than at 100 °C. On the other hand, the cells based on the Ca-Li-K and Ca-Na-K MSEs exhibited great reproducibility also at lower temperatures. At 60 °C, all cells except the one based on the Ca-Li-K MSE failed immediately. Invoking the role of the glass transition temperature (T_g), which is suggested to affect the free volume in MSEs, where a lower T_g indicates weaker ion-ion interactions [16], could explain why the cell based on the Ca-Li-K MSE, the MSE with the lowest T_g , cycles the best at 60 °C. Overall, the best cyclability is observed for the cells based on the Ca-Na-K MSE, suggesting that the charge density of the additional cations ($\text{Li}^+ > \text{Na}^+ > \text{K}^+$) has the most significant effect; the lowest cation charge density provides the best cycling. Following this logic, binary MSEs, such as Ca-K, could potentially generate even better cyclability and in addition be less complex. However, the lowest T_m of binary Ca-based MSE is found at 95 °C (Table S1). Designing feasible MSEs for

CMBs is thus a delicate balancing act between design requirements vs. internal dynamics; increased ΔS_{mix} is not strictly necessary for better cyclability, but is vital for lowering the T_m . However, when selecting additional cations to lower the T_m , those with lower charge density should, as a first approximation, be prioritized for improved cyclability. With this in mind, only the most successful MSE, Ca-Na-K, was tested further.

As the voltage hysteresis remains high, but only upon reduction, and the results above come from 2-electrode cells, neither the mechanism behind nor the limiting factor for this phenomenon can be determined from any reference electrode. Overall, cells using MSEs pose significant challenges for creating practical 3-electrode cells; in Swagelok cells, achieving sufficient contact with the reference electrode is troublesome, and in beaker cells, an enormous amount of expensive salt is required. Our remedy chosen here was heavily inspired by symmetric cathode testing [22]; to first cycle two identical symmetric Ca|Ca-Na-K|Ca design B cells (Fig. S2), whereafter the cells were split, and the two pre-reduced (pre-oxidized) electrodes were paired together and assembled into design C cells and cycled (Fig. 4).

Comparing the OCVs shows that the pre-reduced cell is stable at ~3

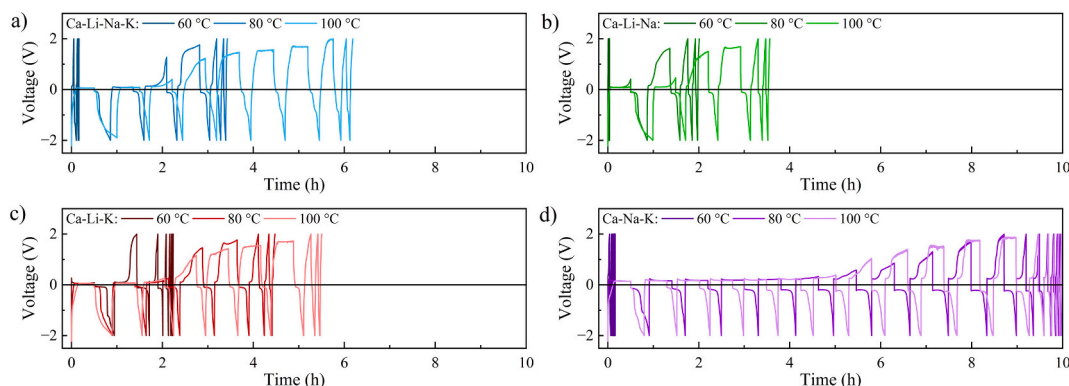


Fig. 3. Symmetric Ca||Ca cells cycled at 60, 80, and 100 °C, according to cell design B, based on: a) Ca-Li-Na-K, b) Ca-Li-Na, c) Ca-Li-K, and d) Ca-Na-K MSEs.

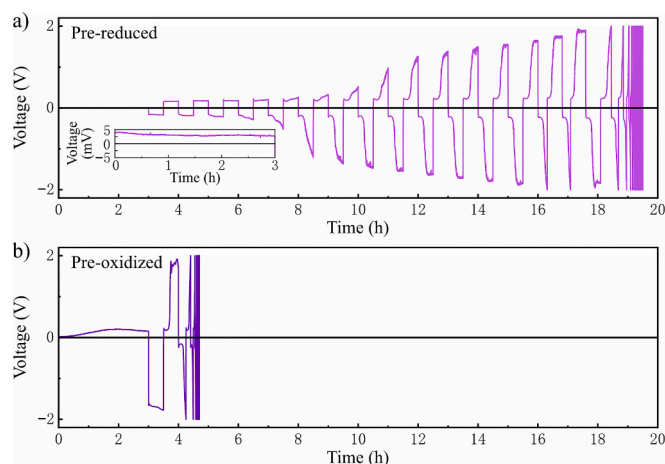


Fig. 4. Design C cells using the Ca-Na-K MSE: a) pre-reduced and b) pre-oxidized.

mV, while the pre-oxidized cell eventually stabilizes at a vastly larger ~ 160 mV. The former cell's electrodes are thus likely very pure Ca metal plated on the surfaces, whereas the latter cell's electrodes have different interphases/interfaces in relation to each other. When galvanostatic cycling begins after 3 h, the latter immediately exhibits very high voltage hysteresis, leading to rapid failure, while the former shows several cycles with much lower voltage hysteresis, both upon reduction and oxidation, before the polarization gradually increases. Our initial working hypothesis, based on cell design A tests (Fig. 1b), that the transition from a lower, flattened-out voltage hysteresis to a rapid increase in voltage hysteresis, was attributable to stripping of fresh deposit followed by stripping of bulk calcium, is thus strengthened by these new data. This as the pre-reduced cell – arguably the one with the most accessible fresh deposit – cycles much better than the pre-oxidized cell. Our design C cells thus tell us, both that we most likely cannot create any full cells using the Ca|Ca-Na-K combination as is, but also that there might be options to improve the cyclability by calcium metal pre-plating and/or other pre-treatments, strategies that are quite common for metal battery technologies other than CMBs [14,23,24].

4. Concluding remarks

The proof-of-concept analysis presented here demonstrates that employing semi-solid MSEs to create high-temperature CMBs can be a feasible route forward. Still, it will require quite some further fine-tuning of the setup and/or the metal anode surfaces to be anywhere close to practical. Furthermore, we acknowledge that only symmetric Ca|Ca cells are presented herein, and that for real battery application full cell configuration tests are a necessity. Cathodes for CMBs are being researched in parallel, but very few have been found, and those tested/compatible for high-temperature applications are scarce/non-existent. Nevertheless, for any advancement of challenging NGB technologies beyond lithium-ion and sodium-ion batteries, with large fundamental promises in terms of performance and safety etc., such as for high-temperature CMBs, unconventional cell designs – such as the present attempt and direction, might be needed.

CRediT authorship contribution statement

Johanna Timhagen: Writing – original draft, Visualization, Investigation, Formal analysis. **Alexandre Ponrouch:** Writing – review & editing, Supervision. **Jonathan Weidow:** Supervision. **Patrik Johansson:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to gratefully acknowledge the financial support from the Swedish Research Council (grants #2020–03988 and #2021–00613). A.P. gratefully acknowledges funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement no. 101089281) and the Spanish Agencia Estatal de Investigación SeveroOchoa Program for Centres of Excellence in R&D (CEX2023-001263-S).

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.elecom.2026.108154>.

Data availability

Data will be made available on request.

References

- [1] IEA, Global Energy Rev. (2025) 2025. <https://www.iea.org/reports/global-energy-review-2025>.
- [2] The battery report 2024, Volta Foundation (2025). https://report.volta.foundation/annual-battery-report/public/Battery_Report_2024.pdf.
- [3] Y. Gao, Z. Pan, J. Sun, Z. Liu, J. Wang, High-energy batteries: beyond lithium-ion and their long road to commercialisation, *Nanomicro Lett.* 14 (2022) 94, <https://doi.org/10.1007/s40820-022-00844-2>.
- [4] J. Liu, J. Xiao, J. Yang, W. Wang, Y. Shao, P. Liu, M.S. Whittingham, The TWh challenge: next generation batteries for energy storage and electric vehicles, *Next Energy* 1 (2023) 100015, <https://doi.org/10.1016/j.nxener.2023.100015>.
- [5] P. Molaiyan, S. Bhattacharyya, G.S. dos Reis, R. Sliz, A. Paoletta, U. Lassi, Towards greener batteries: sustainable components and materials for next-generation batteries, *Green Chem.* 26 (2024) 7508–7531, <https://doi.org/10.1039/d3gc05027k>.
- [6] Y. Li, S. Kumar, G. Yang, J. Lu, Y. Yao, K. Kang, Z.W. Seh, The contrast between monovalent and multivalent metal battery anodes, *Science* 2025 (390) (1979) 1–11, <https://doi.org/10.1126/science.adl5482>.
- [7] G. Brunklaus, P. Lennartz, M. Winter, Metal electrodes for next-generation rechargeable batteries, *Nat. Rev. Electr. Eng.* 1 (2024) 79–92, <https://doi.org/10.1038/s44287-023-00006-5>.
- [8] Y. Feng, L. Zhou, H. Ma, Z. Wu, Q. Zhao, H. Li, K. Zhang, J. Chen, Challenges and advances in wide-temperature rechargeable lithium batteries, *Eng. Environ. Sci.* 15 (2022) 1711–1759, <https://doi.org/10.1039/d1ee03292e>.
- [9] D. Guo, Z. Shi, J.K. El-Demellawi, W. Wahyudi, M. Arsalan, H. Zhang, H. N. Alshareef, Lithium metal batteries for high temperature environments, *Adv. Energy Mater.* 15 (2025) e02943, <https://doi.org/10.1002/aenm.202502943>.
- [10] W.M. Haynes, D.R. Lide, T.J. Bruno, Abundance of elements in the earth's crust and in the sea, CRC Press, In *CRC Handbook of Chemistry and Physics*, 2017, pp. 14–17.
- [11] J. Bitenc, A. Ponrouch, R. Dominko, P. Johansson, M.R. Palacin, Multivalent charge carriers, in: *Encyclopedia of Electrochemistry, Batteries*; Wiley, 2020, pp. 1–36, <https://doi.org/10.1002/9783527610426.bard110020>.
- [12] A. Ponrouch, C. Frontera, F. Bardé, M.R. Palacin, Towards a calcium-based rechargeable battery, *Nat. Mater.* 15 (2016) 169–172, <https://doi.org/10.1038/nmat4462>.
- [13] D. Wang, X. Gao, Y. Chen, L. Jin, C. Kuss, P.G. Bruce, Plating and stripping calcium in an organic electrolyte, *Nat. Mater.* 17 (2018) 16–20, <https://doi.org/10.1038/NMAT5036>.
- [14] J. Forero-Saboya, C. Davoisne, R. Dedryvère, I. Yousef, P. Canepa, A. Ponrouch, Understanding the nature of the passivation layer enabling reversible calcium plating, *Eng. Environ. Sci.* 13 (2020) 3423–3431, <https://doi.org/10.1039/d0ee02347g>.
- [15] Q. Zhao, S. Stalin, C.Z. Zhao, L.A. Archer, Designing solid-state electrolytes for safe, energy-dense batteries, *Nat. Rev. Mater.* 5 (2020) 229–252, <https://doi.org/10.1038/s41578-019-0165-5>.
- [16] S. Yan, N. Yao, H. Liu, Z. Zhang, Y. Lu, Z. Liu, W. Hou, P. Zhou, H. Zhou, X. Chen, K. Liu, Q. Zhang, Molten salt electrolytes with enhanced Li^+ -transport kinetics for fast-cycling of high-temperature Lithium metal batteries, *Eng. Environ. Sci.* 18 (2025) 1696–1706, <https://doi.org/10.1039/d4ee04657a>.

- [17] M.M. Walz, D. van der Spoel, Microscopic origins of conductivity in molten salts unraveled by computer simulations, *Commun. Chem.* 4 (2021) 1–10, <https://doi.org/10.1038/s42004-020-00446-2>.
- [18] K. Kubota, K. Tamaki, T. Nohira, T. Goto, R. Hagiwara, Electrochemical properties of alkali bis(Trifluoromethylsulfonyl)amides and their eutectic mixtures, *Electrochim. Acta* 55 (2010) 1113–1119, <https://doi.org/10.1016/j.electacta.2009.09.024>.
- [19] K. Kubota, T. Nohira, R. Hagiwara, New inorganic ionic liquids possessing low melting temperatures and wide electrochemical windows: ternary mixtures of alkali bis(Fluorosulfonyl)amides, *Electrochim. Acta* 66 (2012) 320–324, <https://doi.org/10.1016/j.electacta.2012.01.097>.
- [20] J. Timhagen, C. Cruz, J. Weidow, P. Johansson, Local structure and entropic stabilization of ca-based molten salt electrolytes, *Batter. Supercaps* 7 (2024) e202400297, <https://doi.org/10.1002/batt.202400297>.
- [21] C. Cruz, P. Johansson, Local structure and dynamics in solvent-free molten salt Ca^{2+} -electrolytes, *ChemPhysChem* 26 (2025) e202500090, <https://doi.org/10.1002/cphc.202500090>.
- [22] O. Lužanin, J. Moškon, T. Pavčnik, R. Dominko, J. Bitenc, Unveiling true limits of electrochemical performance of organic cathodes in multivalent batteries through cyclable symmetric cells, *Batter. Supercaps* 6 (2023) e202200437, <https://doi.org/10.1002/batt.202200437>.
- [23] N. Delaporte, Y. Wang, K. Zaghib, Pre-treatments of lithium foil surface for improving the cycling life of Li metal batteries, *Front. Mater.* 6 (2019) 267, <https://doi.org/10.3389/fmats.2019.00267>.
- [24] J. Lee, J. Kim, S. Kim, C. Jo, J. Lee, A review on recent approaches for designing the SEI layer on sodium metal anodes, *Mater. Adv.* 1 (2020) 3143–3166, <https://doi.org/10.1039/d0ma00695e>.