INORGANIC CHEMISTRY FRONTIERS

CHINESE CHEMICAL SOCIETY · ROYAL SOCIETY OF CHEMISTRY

REVIEW

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View Journal

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Cite this: Inorg. Chem. Front., 2024, 11, 1949

Critical insights into the recent advancements and future prospects of zinc ion battery electrolytes in aqueous systems

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Received 6th January 2024,
Accepted 18th February 2024

DOI: 10.1039/d4qi00034j

rsc.li/frontiers-inorganic

In recent years, aqueous zinc ion batteries (ZIBs) have emerged as promising candidates for energy storage systems due to their inherent safety, environmental friendliness, and cost-effectiveness. This review provides a comprehensive overview of the advancements and prospects of aqueous electrolytes for ZIBs. The introduction outlines the background and significance of ZIBs, emphasizing their advantages over organic electrolytes while elucidating challenges and limitations associated with aqueous electrolytes. The foundational knowledge section revisits the fundamental principles of ZIBs, including their basic working mechanism and the composition and properties of aqueous electrolytes. Subsequently, the review delves into the recent research developments, highlighting the design and synthesis of novel aqueous electrolytes and discussing key technological breakthroughs in advanced electrolyte formulations. Relevant research works are presented to provide concrete examples of ongoing progress in this field. This review concludes by summarizing the latest advancements in aqueous electrolytes for ZIBs and emphasizing the significance and potential of this research area. Furthermore, future trends, challenges faced, and potential solutions are discussed, shedding light on the evolving role of ZIBs in the energy sector. Overall, this review serves as a valuable resource for researchers, scientists, and engineers working on the development of advanced energy storage technologies.

1. Introduction

With the global demand for energy on the rise and the increasing need for sustainable solutions, renewable energy sources have taken the center stage.[1,2] The integration of intermittent sources like solar and wind power into the energy grid necessitates efficient and reliable energy storage.[3–5] While lithium-ion batteries have played a pivotal role in the portable electronics and automotive sectors, challenges such as high costs, lithium resource depletion, toxic electrolytes, and security concerns have prompted the exploration of alternative energy storage technologies.[6,7]

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Against this backdrop, ZIBs have emerged as a promising solution, capturing the attention of both researchers and industries.[8] The electrolyte in ZIBs serves as a crucial component, facilitating the transport of Zn^{2+} between the cathode and anode, thereby influencing electrochemically stable potential windows (ESPWs) and coulombic efficiencies (CE) for Zn^{2+} storage.[9] Various electrolytes have been explored for ZIBs, including aqueous (*e.g.*, 3 M $Zn(CF_3SO_3)_2$, H_2O),[10] ionic liquids (*e.g.*, 1-vinyl-3-ethylimidazolium dicyanamide + $Zn(CH_3COO)_2$, 1-ethyl-3-methylimidazolium dicyanamide),[11] organic (*e.g.*, 1-phenylethylamine hydrochloride),[12] gel (*e.g.*, polyethylene glycol methacrylate),[13] and quasi-solid/all-solid formulations (*e.g.*, dimethyl sulfoxide).[14] Among these, water-based electrolytes stand out for their enhanced safety, environmental friendliness, and economic viability. Moreover, they offer a sustainable energy storage option.[15,16] The innovative design of aqueous electrolytes is fundamental to the success of these cutting-edge batteries, addressing the limitations posed by traditional lithium-ion technology.

ZIBs consist of a cathode, an anode, a separator, and an electrolyte, with the aqueous electrolyte serving as a crucial medium for transporting Zn^{2+} between the cathode and the anode.[17,18] The schematic representation of the aqueous ZIBs'