# STUDY ON THE IONIC CONDUCTION PROPERTIES OF ALGINATE-POLY (VINYL ALCOHOL) DOPED AMMONIUM NITRATE BASED BIO-POLYMER BLEND ELECTROLYTES

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## SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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# STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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# ABSTRAK

Penggunaan biobahan di dalam penghasilan elektrolit polimer, khususnya di dalam peranti elektrokimia, pada masa ini mendapat perhatian yang tinggi. Ini kerana elektrolit yang berasaskan biopolimer berpotensi untuk mengurangkan isu persekitaran, pelupusan sisa, dan kebimbangan terhadap kesihatan manusia melalui penggunaan bahan tidak berbahaya di dalam sistem peranti tenaga. Matlamat penyelidikan ini adalah untuk mencipta dan mencirikan sistem biopolimer campuran elektrolit (BBEs) yang diperbuat daripada alginat yang dicampur dengan alkohol polivinil (PVA) sebagai perumah biopolimer dan didop dengan kandungan garam ionik ammonium nitrat ($NH_4NO_3$) yang berbeza. Sistem BBEs telah dihasilkan menggunakan kaedah penuangan larutan, dan filem yang terhasil menunjukkan rupa yang lut sinar, berdiri bebas, dan fleksibel. Spektroskopi inframerah jelmaan Fourier (FTIR) telah digunakan untuk mengesahkan pengkompleksan yang berlaku di dalam BBEs. Analisis belauan sinar-x (XRD) dan mikroskopi elektron pengimbasan (SEM) telah digunakan untuk mendedahkan sifat amorf dan morfologi BBEs. Keputusan analisis termogravimetri (TGA) menunjukkan bahawa kestabilan haba BBEs telah dipertingkatkan hasil daripada penambahan $NH_4NO_3$. Spektroskopi impedans elektrik (EIS) telah digunakan untuk mengukur kekonduksian ionik sistem BBEs, di mana kekonduksian tertinggi didedahkan pada $5.20 \times 10^{-4}$ S $cm^{-1}$ apabila 35 wt.% $NH_4NO_3$ ditambah ke dalam sistem. Peningkatan kekonduksian ionik pada suhu bilik adalah disebabkan oleh sifat amorf yang telah dipertingkatkan serta pengkompleksan antara oksigen pasangan tersendiri pada rantai tulang belakang biopolimer Alg-PVA dan $H^+$ daripada $NH_4NO_3$. Kesan suhu pada kekonduksian ionik BBEs mendedahkan bahawa semua BBEs mematuhi tingkah laku Arrhenius dan memaparkan tenaga pengaktifan, $E_a$ yang rendah iaitu pada 0.10 eV bagi BBEs dengan konduksi tertinggi. Berdasarkan analisis daripada tindak balas dielektrik, pergerakan ion, $\mu$, ketumpatan nombor pembawa cas, $\eta$, dan pekali resapan, $D$ daripada $H^+$ adalah semua faktor yang mempengaruhi kekonduksian ionik BBEs. Melalui penggunaan analisis pengukuran nombor pindahan (TNM), BBEs dengan kekonduksian ionik tertinggi telah dianalisis untuk menentukan dominasi ion. Nombor pindahan ion yang telah dijumpai adalah 0.51, dan penemuan ini mengesahkan keulungan ion di dalam elektrolit biopolimer. Berdasarkan keputusan ini, sistem BBEs ini mempunyai potensi besar untuk digunakan di dalam aplikasi peranti elektrokimia sebagai elektrolit khususnya di dalam kapasitans dua lapisan elektrik dan bateri proton.

## ABSTRACT

The utilization of biomaterial in the production of polymer electrolytes, particularly in electrochemical devices, is currently receiving a great deal of attention. This is because these bio-polymer-based electrolytes have the potential to alleviate the environmental issues, disposal of waste, and human-health concerns through the usage of non-hazardous materials in the energy device system. The aim of this research is to create and characterize a bio-polymer blend electrolyte (BBEs) system made from alginate blended with poly (vinyl alcohol) (PVA) as the bio-polymer host and doped with different contents of ammonium nitrate ($NH_4NO_3$) ionic salt. The BBEs system was developed using the solution casting method, and the resulting films showed a transparent, free-standing, and flexible appearance. Fourier transform infrared (FTIR) spectroscopy was used to confirm the complexation occurs in the BBEs. X-ray diffraction (XRD) analysis and scanning electron microscopy (SEM) were used to reveal the amorphous nature and morphology of the BBEs. The results of the thermogravimetric analysis (TGA) showed that the thermal stability of the BBEs has been enhanced as a result of the addition of $NH_4NO_3$. Electrical impedance spectroscopy (EIS) was used to measure the ionic conductivity of the BBEs system, where the highest ionic conductivity was revealed to be $5.20 \times 10^{-4}$ S cm$^{-1}$ when 35 wt.% of $NH_4NO_3$ was added into the system. The increase of ionic conductivity at room temperature was due to the enhanced amorphous nature as well as complexation between the lone pair oxygen at the Alg-PVA bio-polymer chain backbone and $H^+$ from $NH_4NO_3$. The effect of temperature on the ionic conductivity of BBEs revealed that all BBEs obeyed Arrhenius behavior and displayed a lower activation energy, $E_a$ of 0.10 eV for the highest conducting BBEs. Based on the dielectric response analysis, it was revealed that the ionic mobility, $\mu$, number density of charge carriers, $\eta$, and diffusion coefficient, $D$ of the $H^+$ were all factors that influenced the ionic conductivity of the BBEs. Through the use of transference number measurement (TNM) analysis, the BBEs with the greatest ionic conductivity was analyzed to determine the ion dominancy. The $t_{ion}$ was found to be 0.51, and this finding verified the predominance of $H^+$ in the present BBEs system. Based on these results, this BBEs system has a high potential to be utilized in electrochemical device applications as an electrolyte, specifically in electrical double layer capacitors and proton batteries.

## TABLE OF CONTENT

# REFERENCES


Abdulkadir, B. A., Dennis, J. O., Al-Hadeethi, Y., Shukur, M. F. B. A., Mkawi, E. M., Al-Harbi, N., Ibnaouf, K. H., Aldaghri, O., Usman, F., & Abbas Adam, A. (2021). Optimization of the electrochemical performance of a composite polymer electrolyte based on PVA-$K_2CO_3$-$SiO_2$ composite. *Polymers, 13*(1), 1–24. https://doi.org/10.3390/polym13010092

Abdulkadir, B. A., Dennis, J. O., Fadhlullah Bin Abd. Shukur, M., Elsayed Nasef, M. M., & Usman, F. (2020). Preparation and characterization of gel polymer electrolyte based on PVA-$K_2CO_3$. *Polymer-Plastics Technology and Materials*, *59*(15), 1679–1697. https://doi.org/10.1080/25740881.2020.1765380

Abdulkareem, S. S. (2021). Structural, morphological and electrical properties of chitosan/methylcellulose blend polymer doped with different concentrations of $NH_4NO_3$. *Materials Research Express*, *8*(8), 086301. https://doi.org/10.1088/2053-1591/ac1d69

Abdullah, O. G., Aziz, S. B., & Rasheed, M. A. (2018). Incorporation of $NH_4NO_3$ into MC-PVA blend-based polymer to prepare proton-conducting polymer electrolyte films. *Ionics*, *24*(3), 777–785. https://doi.org/10.1007/s11581-017-2228-1

Abisharani, J. M., Balamurugan, S., Thomas, A., Devikala, S., Arthanareeswari, M., Ganesan, S., & Prakash, M. (2021). Incorporation of organic additives with electron rich donors (N, O, S) in gelatin gel polymer electrolyte for dye sensitized solar cells. *Solar Energy*, *218*, 552–562. https://doi.org/10.1016/j.solener.2021.03.007

Ahmed, H. T., & Abdullah, O. G. (2019). Preparation and composition optimization of PEO: MC polymer blend films to enhance electrical conductivity. *Polymers*, *11*(5). https://doi.org/10.3390/polym11050853

Alias, S. S., Chee, S. M., & Mohamad, A. A. (2017). Chitosan–ammonium acetate–ethylene carbonate membrane for proton batteries. *Arabian Journal of Chemistry*, *10*, S3687–S3698. https://doi.org/10.1016/j.arabjc.2014.05.001

Aljafari, B., Alamro, T., Ram, M. K., & Takshi, A. (2019). Polyvinyl alcohol-acid redox active gel electrolytes for electrical double-layer capacitor devices. *Journal of Solid State Electrochemistry*, *23*(1), 125–133. https://doi.org/10.1007/s10008-018-4120-y

Alves, R., Sentanin, F., Sabadini, R. C., Fernandes, M., de Zea Bermudez, V., Pawlicka, A., & Silva, M. M. (2018). Samarium (III) triflate-doped chitosan electrolyte for solid state electrochromic devices. *Electrochimica Acta*, *267*, 51–62. https://doi.org/10.1016/j.electacta.2018.02.044

Alves, R., Sentanin, F., Sabadini, R. C., Pawlicka, A., & Silva, M. M. (2018). Green polymer electrolytes of chitosan doped with erbium triflate. *Journal of Non-Crystalline Solids*, *482*, 183–191. https://doi.org/10.1016/j.jnoncrysol.2017.12.038

Ambika, C., Karuppasamy, K., Vikraman, D., Lee, J. Y., Regu, T., Ajith Bosco Raj, T., Prasanna, K., & Kim, H. S. (2018). Effect of dimethyl carbonate (DMC) on the electrochemical and cycling properties of solid polymer electrolytes (PVP-MSA) and its application for proton batteries. *Solid State Ionics*, *321*, 106–114. https://doi.org/10.1016/j.ssi.2018.04.013

Armand, M. (1994). The history of polymer electrolytes. *Solid State Ionics*, *69*(3–4), 309–319. https://doi.org/10.1016/0167-2738(94)90419-7

Arof, A. K., Amirudin, S., Yusof, S. Z., & Noor, I. M. (2014). A method based on impedance spectroscopy to determine transport properties of polymer electrolytes. *Physical Chemistry Chemical Physics*, *16*(5), 1856–1867. https://doi.org/10.1039/c3cp53830c

Arya, A., & Sharma, A. L. (2018). Effect of salt concentration on dielectric properties of Li-ion conducting blend polymer electrolytes. *Journal of Materials Science: Materials in Electronics*, *29*(20), 17903–17920. https://doi.org/10.1007/s10854-018-9905-3

Asnawi, A. S. F. M., Aziz, S. B., Brevik, I., Brza, M. A., Yusof, Y. M., Alshehri, S. M., Ahamad, T., & Kadir, M. F. Z. (2021). The study of plasticized sodium ion conducting polymer blend electrolyte membranes based on chitosan/dextran biopolymers: Ion transport, structural, morphological and potential stability. *Polymers*, *13*(3), 1–25. https://doi.org/10.3390/polym13030383

Awang, F. F., Hassan, M. F., Chan, K. S., & Kamarudin, K. H. (2021). Ion Transport Study in Corn Starch-$NaHSO_3$ Based Polymer Electrolytes. *Scientific Research Journal*, *18*(2), 17–36. https://doi.org/10.24191/srj.v18i2.11985

Aziz, S. B., & Abidin, Z. H. Z. (2013). Electrical Conduction Mechanism in Solid Polymer Electrolytes: New Concepts to Arrhenius Equation. *Journal of Soft Matter*, *2013*, 1–8. https://doi.org/10.1155/2013/323868

Aziz, S. B., Asnawi, A. S. F. M., Abdulwahid, R. T., Ghareeb, H. O., Alshehri, S. M., Ahamad, T., Hadi, J. M., & Kadir, M. F. Z. (2021). Design of potassium ion conducting PVA based polymer electrolyte with improved ion transport properties for EDLC device application. *Journal of Materials Research and Technology*, *13*, 933–946. https://doi.org/10.1016/j.jmrt.2021.05.017

Aziz, S. B., Brza, M. A., Hamsan, M. H., Kadir, M. F. Z., Muzakir, S. K., & Abdulwahid, R. T. (2020). Effect of ohmic-drop on electrochemical performance of EDLC fabricated from PVA:dextran:$NH_4I$ based polymer blend electrolytes. *Journal of Materials Research and Technology*, *9*(3), 3734–3745. https://doi.org/10.1016/j.jmrt.2020.01.110

Aziz, S. B., Brza, M. A., Mishra, K., Hamsan, M. H., Karim, W. O., Abdullah, R. M., Kadir, M. F. Z., & Abdulwahid, R. T. (2020). Fabrication of high performance energy storage EDLC device from proton conducting methylcellulose: dextran polymer blend electrolytes. *Journal of Materials Research and Technology*, *9*(2), 1137–1150. https://doi.org/10.1016/J.JMRT.2019.11.042

Aziz, S. B., Dannoun, E. M. A., Hamsan, M. H., Ghareeb, H. O., Nofal, M. M., Karim, W. O., Asnawi, A. S. F. M., Hadi, J. M., & Kadir, M. F. Z. A. (2021). A polymer blend electrolyte based on cs with enhanced ion transport and electrochemical properties for electrical double layer capacitor applications. *Polymers*, *13*(6). https://doi.org/10.3390/polym13060930

Aziz, S. B., Hamsan, M. H., Abdullah, R. M., & Kadir, M. F. Z. (2019). A promising polymer blend electrolytes based on chitosan: Methyl cellulose for EDLC application with high specific capacitance and energy density. *Molecules*, *24*(13), 2503. https://doi.org/10.3390/molecules24132503

Aziz, S. B., Hamsan, M. H., Brza, M. A., Kadir, M. F. Z., Abdulwahid, R. T., Ghareeb, H. O., &

Woo, H. J. (2019). Fabrication of energy storage EDLC device based on CS:PEO polymer blend electrolytes with high $Li^+$ ion transference number. *Results in Physics*, *15*, 102584. https://doi.org/10.1016/j.rinp.2019.102584

Aziz, S. B., Hamsan, M. H., Kadir, M. F. Z., Karim, W. O., & Abdullah, R. M. (2019). Development of polymer blend electrolyte membranes based on chitosan: Dextran with high ion transport properties for EDLC application. *International Journal of Molecular Sciences*, *20*(13), 3369. https://doi.org/10.3390/ijms20133369

Aziz, S. B., Hamsan, M. H., Karim, W. O., Kadir, M. F. Z., Brza, M. A., & Abdullah, O. G. (2019). High proton conducting polymer blend electrolytes based on chitosan: Dextran with constant specific capacitance and energy density. *Biomolecules*, *9*(7), 267. https://doi.org/10.3390/biom9070267

Aziz, S. B., Woo, T. J., Kadir, M. F. Z., & Ahmed, H. M. (2018). A conceptual review on polymer electrolytes and ion transport models. In *Journal of Science: Advanced Materials and Devices* (Vol. 3, Issue 1, pp. 1–17). Elsevier. https://doi.org/10.1016/j.jsamd.2018.01.002

Buraidah, M. H., & Arof, A. K. (2011). Characterization of chitosan/PVA blended electrolyte doped with NH 4I. *Journal of Non-Crystalline Solids*, *357*(16–17), 3261–3266. https://doi.org/10.1016/j.jnoncrysol.2011.05.021

Chee, S. Y., Wong, P. K., & Wong, C. L. (2011). Extraction and characterisation of alginate from brown seaweeds (Fucales, Phaeophyceae) collected from Port Dickson, Peninsular Malaysia. *Journal of Applied Phycology*, *23*(2), 191–196. https://doi.org/10.1007/s10811-010-9533-7

Dhatarwal, P., & Sengwa, R. J. (2020). Dielectric relaxation, Li-ion transport, electrochemical, and structural behaviour of PEO/PVDF/$LiClO_4$/$TiO_2$/PC-based plasticized nanocomposite solid polymer electrolyte films. *Composites Communications*, *17*, 182–191. https://doi.org/10.1016/j.coco.2019.12.006

Dzulkipli, M. Z., Ahmad, A., Su'ait, M. S., Noor, S. A. M., Dzulkurnain, N. A., Karim, J., & Hassan, N. H. (2019). Studies on electrochemical behaviour of PVdF-HFP based ionic liquid gel polymer electrolyte. *AIP Conference Proceedings*, *2111*(1), 050006. https://doi.org/10.1063/1.5111254

Epp, J. (2016). X-Ray Diffraction (XRD) Techniques for Materials Characterization. In *Materials Characterization Using Nondestructive Evaluation (NDE) Methods* (pp. 81–124). Elsevier Inc. https://doi.org/10.1016/B978-0-08-100040-3.00004-3

Fan, P., Liu, H., Marosz, V., Samuels, N. T., Suib, S. L., Sun, L., & Liao, L. (2021). High Performance Composite Polymer Electrolytes for Lithium-Ion Batteries. In *Advanced Functional Materials* (Vol. 31, Issue 23). John Wiley and Sons Inc. https://doi.org/10.1002/adfm.202101380

Fang, Z., Zhao, M., Peng, Y., & Guan, S. (2021). Organic ionic plastic crystal enhanced interface compatibility of PEO-based solid polymer electrolytes for lithium-metal batteries. *Solid State Ionics*, *373*, 115806. https://doi.org/10.1016/j.ssi.2021.115806

Farah, N., Ng, H. M., Numan, A., Liew, C. W., Latip, N. A. A., Ramesh, K., & Ramesh, S. (2019). Solid polymer electrolytes based on poly(vinyl alcohol) incorporated with sodium salt and ionic liquid for electrical double layer capacitor. *Materials Science and Engineering B:*

*Solid-State Materials for Advanced Technology*, *251*. https://doi.org/10.1016/j.mseb.2019.114468

Feig, V. R., Tran, H., & Bao, Z. (2018). Biodegradable Polymeric Materials in Degradable Electronic Devices. *ACS Central Science*, *4*(3), 337–348. https://doi.org/10.1021/acscentsci.7b00595

Fenton, D. E., Parker, J. M., & Wright, P. V. (1973). Complexes of alkali metal ions with poly(ethylene oxide). *Polymer*, *14*(11), 589. https://doi.org/10.1016/0032-3861(73)90146-8

Fu, J., Li, Z., Zhou, X., & Guo, X. (2022). Ion transport in composite polymer electrolytes. In *Materials Advances* (Vol. 3, Issue 9, pp. 3809–3819). Royal Society of Chemistry. https://doi.org/10.1039/d2ma00215a

Fuzlin, A. F., Nagao, Y., Misnon, I. I., & Samsudin, A. S. (2020). Studies on structural and ionic transport in biopolymer electrolytes based on alginate-LiBr. *Ionics*, *26*(4), 1923–1938. https://doi.org/10.1007/s11581-019-03386-7

Fuzlin, A. F., Saadiah, M. A., Hasan, M. M., Nagao, Y., Misnon, I. I., & Samsudin, A. S. (2022). Involvement of ethylene carbonate on the enhancement $H^+$ carriers in structural and ionic conduction performance on alginate bio-based polymer electrolytes. *International Journal of Hydrogen Energy*. https://doi.org/10.1016/j.ijhydene.2021.12.124

Fuzlin, A. F., Saadiah, M. A., Yao, Y., Nagao, Y., & Samsudin, A. S. (2020). Enhancing proton conductivity of sodium alginate doped with glycolic acid in bio-based polymer electrolytes system. *Journal of Polymer Research*, *27*(8), 1–16. https://doi.org/10.1007/s10965-020-02142-0

Fuzlin, A. F., & Samsudin, A. S. (2021). Studies on favorable ionic conduction and structural properties of biopolymer electrolytes system-based alginate. *Polymer Bulletin*, *78*(4), 2155–2175. https://doi.org/10.1007/s00289-020-03207-2

Gezerman, A. O. (2020). A novel industrial-scale strategy to prevent degradation and caking of ammonium nitrate. *Heliyon*, *6*(3), e03628. https://doi.org/10.1016/j.heliyon.2020.e03628

Ghani, N. A. A., Othaman, R., Ahmad, A., Anuar, F. H., & Hassan, N. H. (2019). Impact of purification on iota carrageenan as solid polymer electrolyte. *Arabian Journal of Chemistry*, *12*(3), 370–376. https://doi.org/10.1016/j.arabjc.2018.06.008

Ghazali, N. M., Mazuki, N. F., & Samsudin, A. S. (2021). Characterization of Biopolymer Blend-based on Alginate and Poly (vinyl Alcohol) as an Application for Polymer Host in Polymer Electrolyte. *IOP Conference Series: Materials Science and Engineering*, *1092*(1), 012047. https://doi.org/10.1088/1757-899x/1092/1/012047

Ghazali, N. M., & Samsudin, A. S. (2020). Progress on biopolymer as an application in electrolytes system: A review study. *Materials Today: Proceedings*, *49*, 3668–3678. https://doi.org/10.1016/j.matpr.2021.09.473

Gohel, K., & Kanchan, D. K. (2019). Effect of PC:DEC plasticizers on structural and electrical properties of PVDF–HFP:PMMA based gel polymer electrolyte system. *Journal of Materials Science: Materials in Electronics*, *30*(13), 12260–12268. https://doi.org/10.1007/s10854-019-01585-6

Gohel, K., Kanchan, D. K., MacHhi, H. K., Soni, S. S., & Maheshwaran, C. (2020). Gel polymer electrolyte based on PVDF-HFP:PMMA incorporated with propylene carbonate (PC) and diethyl carbonate (DEC) plasticizers : electrical, morphology, structural and electrochemical properties. *Materials Research Express*, *7*(2), 25301. https://doi.org/10.1088/2053-1591/ab6c06

Gonçalves, R., Miranda, D., Almeida, A. M., Silva, M. M., Meseguer-Dueñas, J. M., Ribelles, J. L. G., Lanceros-Méndez, S., & Costa, C. M. (2019). Solid polymer electrolytes based on lithium bis(trifluoromethanesulfonyl)imide/poly(vinylidene fluoride -co-hexafluoropropylene) for safer rechargeable lithium-ion batteries. *Sustainable Materials and Technologies*, *21*, e00104. https://doi.org/10.1016/j.susmat.2019.e00104

Gong, S. D., Huang, Y., Cao, H. J., Lin, Y. H., Li, Y., Tang, S. H., Wang, M. S., & Li, X. (2016). A green and environment-friendly gel polymer electrolyte with higher performances based on the natural matrix of lignin. *Journal of Power Sources*, *307*, 624–633. https://doi.org/10.1016/j.jpowsour.2016.01.030

Hadi, J. M., Aziz, S. B., Mustafa, M. S., Brza, M. A., Hamsan, M. H., Kadir, M. F. Z., Ghareeb, H. O., & Hussein, S. A. (2020). Electrochemical impedance study of proton conducting polymer electrolytes based on PVC doped with thiocyanate and plasticized with glycerol. *International Journal of Electrochemical Science*, *15*, 4671–4683. https://doi.org/10.20964/2020.05.34

Hadi, J. M., Aziz, S. B., Nofal, M. M., Hussen, S. A., Hamsan, M. H., Brza, M. A., Abdulwahid, R. T., Kadir, M. F. Z., & Woo, H. J. (2020). Electrical, dielectric property and electrochemical performances of plasticized silver ion-conducting chitosan-based polymer nanocomposites. *Membranes*, *10*(7), 1–22. https://doi.org/10.3390/membranes10070151

Hafiza, M. N., & Isa, M. I. N. (2017). Solid polymer electrolyte production from 2-hydroxyethyl cellulose: Effect of ammonium nitrate composition on its structural properties. *Carbohydrate Polymers*, *165*, 123–131. https://doi.org/10.1016/j.carbpol.2017.02.033

Hamsan, M. H., Aziz, S. B., Azha, M. A. S., Azli, A. A., Shukur, M. F., Yusof, Y. M., Muzakir, S. K., Manan, N. S. A., & Kadir, M. F. Z. (2020). Solid-state double layer capacitors and protonic cell fabricated with dextran from Leuconostoc mesenteroides based green polymer electrolyte. *Materials Chemistry and Physics*, *241*. https://doi.org/10.1016/j.matchemphys.2019.122290

Hamsan, M. H., Aziz, S. B., Shukur, M. F., & Kadir, M. F. Z. (2019). Protonic cell performance employing electrolytes based on plasticized methylcellulose-potato starch-$NH_4NO_3$. *Ionics*, *25*(2), 559–572. https://doi.org/10.1007/s11581-018-2827-5

Hamsan, M. H., Shukur, M. F., & Kadir, M. F. Z. (2017). The effect of $NH_4NO_3$ towards the conductivity enhancement and electrical behavior in methyl cellulose-starch blend based ionic conductors. *Ionics*, *23*(5), 1137–1154. https://doi.org/10.1007/s11581-016-1918-4

Hasan, M. M., Islam, M. D., & Rashid, T. U. (2020). Biopolymer-based electrolytes for dye-sensitized solar cells: A critical review. *Energy and Fuels*, *34*(12), 15634–15671. https://doi.org/10.1021/acs.energyfuels.0c03396

Hassan, M. F., & Azimi, N. S. N. (2019). Conductivity and transport properties of starch/glycerin-MgSO4 solid polymer electrolytes. *International Journal of ADVANCED AND APPLIED SCIENCES*, *6*(5), 38–43. https://doi.org/10.21833/ijaas.2019.05.007

Hassan, M. F., Zainuddin, S. K., Kamarudin, K. H., Sheng, C. K., & Adha Abdullah, M. A. (2018). Ion-conducting polymer electrolyte films based on poly (Sodium 4-styrenesulfonate) complexed with ammonium nitrate: Studies based on morphology, structural and electrical spectroscopy. *Malaysian Journal of Analytical Sciences*, *22*(2), 238–248. https://doi.org/10.17576/mjas-2018-2202-08

Hegde, S., Ravindrachary, V., Praveena, S. D., Ismayil, Guruswamy, B., & Sagar, R. N. (2020). Microstructural, dielectric, and transport properties of proton-conducting solid polymer electrolyte for battery applications. *Ionics*, *26*(5), 2379–2394. https://doi.org/10.1007/s11581-019-03383-w

Heidari, M., Khomeiri, M., Yousefi, H., Rafieian, M., & Kashiri, M. (2021). Chitin nanofiber-based nanocomposites containing biodegradable polymers for food packaging applications. *Journal Fur Verbraucherschutz Und Lebensmittelsicherheit*, *16*(3), 237–246. https://doi.org/10.1007/s00003-021-01328-y

Hosseinioun, A., & Paillard, E. (2020). In situ crosslinked PMMA gel electrolyte from a low viscosity precursor solution for cost-effective, long lasting and sustainable lithium-ion batteries. *Journal of Membrane Science*, *594*. https://doi.org/10.1016/j.memsci.2019.117456

Hu, J., Wang, W., Zhou, B., Feng, Y., Xie, X., & Xue, Z. (2019). Poly(ethylene oxide)-based composite polymer electrolytes embedding with ionic bond modified nanoparticles for all-solid-state lithium-ion battery. *Journal of Membrane Science*, *575*, 200–208. https://doi.org/10.1016/J.MEMSCI.2019.01.025

Jafari, H., & Rahimpour, M. R. (2020). Pb Acid Batteries. In *Rechargeable Batteries* (pp. 17–39). Wiley. https://doi.org/10.1002/9781119714774.ch2

Karaman, B., & Bozkurt, A. (2018). Enhanced performance of supercapacitor based on boric acid doped PVA-H2SO4 gel polymer electrolyte system. *International Journal of Hydrogen Energy*, *43*(12), 6229–6237. https://doi.org/10.1016/j.ijhydene.2018.02.032

Khan, N. M., & Samsudin, A. S. (2021). Electrical conduction of PMMA/PLA doped lithium bis(oxalato) borate based hybrid gel polymer electrolyte. *Materials Today: Proceedings*, *51*, 1460–1464. https://doi.org/10.1016/j.matpr.2021.11.655

Koduru, H. K., Marino, L., Scarpelli, F., Petrov, A. G., Marinov, Y. G., Hadjichristov, G. B., Iliev, M. T., & Scaramuzza, N. (2017). Structural and dielectric properties of $NaIO_4$ – Complexed PEO/PVP blended solid polymer electrolytes. *Current Applied Physics*, *17*(11), 1518–1531. https://doi.org/10.1016/j.cap.2017.07.012

Kurapati, S., Gunturi, S. S., Nadella, K. J., & Erothu, H. (2019). Novel solid polymer electrolyte based on PMMA:$CH_3COOLi$ effect of salt concentration on optical and conductivity studies. *Polymer Bulletin*, *76*(10), 5463–5481. https://doi.org/10.1007/s00289-018-2659-5

Leones, R., Sabadini, R. C., Esperança, J. M. S. S., Pawlicka, A., & Silva, M. M. (2017). Effect of storage time on the ionic conductivity of chitosan-solid polymer electrolytes incorporating cyano-based ionic liquids. *Electrochimica Acta*, *232*, 22–29. https://doi.org/10.1016/j.electacta.2017.02.053

Li, Liansheng, Deng, Y., & Chen, G. (2020). Status and prospect of garnet/polymer solid composite electrolytes for all-solid-state lithium batteries. *Journal of Energy Chemistry*, *50*, 154–177. https://doi.org/10.1016/J.JECHEM.2020.03.017

Li, Libo, Shan, Y., & Yang, X. (2021). New insights for constructing solid polymer electrolytes with ideal lithium-ion transfer channels by using inorganic filler. *Materials Today Communications*, *26*, 101910. https://doi.org/10.1016/j.mtcomm.2020.101910

Liew, C. W., Ramesh, S., & Arof, A. K. (2014). A novel approach on ionic liquid-based poly(vinyl alcohol) proton conductive polymer electrolytes for fuel cell applications. *International Journal of Hydrogen Energy*, *39*(6), 2917–2928. https://doi.org/10.1016/j.ijhydene.2013.07.092

Lim, J. Y., Kang, D. A., Kim, N. U., Lee, J. M., & Kim, J. H. (2019). Bicontinuously crosslinked polymer electrolyte membranes with high ion conductivity and mechanical strength. *Journal of Membrane Science*, *589*, 117250. https://doi.org/10.1016/j.memsci.2019.117250

Mahalakshmi, M., Selvanayagam, S., Selvasekarapandian, S., Moniha, V., Manjuladevi, R., & Sangeetha, P. (2019). Characterization of biopolymer electrolytes based on cellulose acetate with magnesium perchlorate ($Mg(ClO_4)_2$) for energy storage devices. *Journal of Science: Advanced Materials and Devices*, *4*(2), 276–284. https://doi.org/10.1016/j.jsamd.2019.04.006

Maheshwari, T., Tamilarasan, K., Selvasekarapandian, S., Chitra, R., & Muthukrishnan, M. (2022). Synthesis and characterization of Dextran, poly (vinyl alcohol) blend biopolymer electrolytes with $NH_4NO_3$, for electrochemical applications. *International Journal of Green Energy*, *19*(3), 314–330. https://doi.org/10.1080/15435075.2021.1946811

Majid, S. R., & Arof, A. K. (2005). Proton-conducting polymer electrolyte films based on chitosan acetate complexed with $NH_4NO_3$ salt. *Physica B: Condensed Matter*, *355*(1–4), 78–82. https://doi.org/10.1016/j.physb.2004.10.025

Manafi, P., Nazockdast, H., Gomari, S., Manafi, M. R., Sedighi, S., Bertoli, L., & Magagnin, L. (2021). Morphology and electrochemical properties of a gel blend polymer electrolyte based on PVDF-HFP/PEO blend. *Iranian Journal of Polymer Science and Technology*, *34*(1), 55–69. https://doi.org/10.22063/jipst.2021.1793

Manjunath, A., Deepa, T., Supreetha, N. K., & Irfan, M. (2015). Studies on AC Electrical Conductivity and Dielectric Properties of PVA/$NH_4NO_3$ Solid Polymer Electrolyte Films. *Advances in Materials Physics and Chemistry*, *05*(08), 295–301. https://doi.org/10.4236/ampc.2015.58029

Maragani, N., & Vijaya Kumar, K. (2018). Structural and conductivity studies of PAN-based Al 2 O 3 nanocomposite gel polymer electrolytes. *Iranian Journal of Materials Science and Engineering*, *15*(4), 11–18. https://doi.org/10.22068/ijmse.15.4.11

Masoud, E. M., El-Bellihi, A. A., Bayoumy, W. A., & Mohamed, E. A. (2018). Polymer composite containing nano magnesium oxide filler and lithiumtriflate salt: An efficient polymer electrolyte for lithium ion batteries application. *Journal of Molecular Liquids*, *260*, 237–244. https://doi.org/10.1016/J.MOLLIQ.2018.03.084

Mazuki, N., Abdul Majeed, A. P. P., & Samsudin, A. S. (2020). Study on electrochemical properties of CMC-PVA doped $NH_4Br$ based solid polymer electrolytes system as application for EDLC. *Journal of Polymer Research*, *27*(6), 1–13. https://doi.org/10.1007/s10965-020-02078-5

Mazuki, N. F., Abdul Majeed, A. P. P., Nagao, Y., & Samsudin, A. S. (2020). Studies on ionics conduction properties of modification CMC-PVA based polymer blend electrolytes via impedance approach. *Polymer Testing*, *81*(August 2019), 106234. https://doi.org/10.1016/j.polymertesting.2019.106234

Mazuki, N. F., Fuzlin, A. F., Saadiah, M. A., & Samsudin, A. S. (2019). An investigation on the abnormal trend of the conductivity properties of CMC/PVA-doped $NH_4Cl$-based solid biopolymer electrolyte system. *Ionics*, *25*(6), 2657–2667. https://doi.org/10.1007/s11581-018-2734-9

Mazuki, N. F., Kufian, M. Z., Nagao, Y., & Samsudin, A. S. (2022). Correlation Studies Between Structural and Ionic Transport Properties of Lithium-Ion Hybrid Gel Polymer Electrolytes Based PMMA-PLA. *Journal of Polymers and the Environment*, *30*(5), 1864–1879. https://doi.org/10.1007/s10924-021-02317-w

Meng, N., Zhu, X., & Lian, F. (2021). Particles in composite polymer electrolyte for solid-state lithium batteries: A review. *Particuology*. https://doi.org/10.1016/J.PARTIC.2021.04.002

Mindemark, J., Lacey, M. J., Bowden, T., & Brandell, D. (2018). Beyond PEO—Alternative host materials for $Li^+$-conducting solid polymer electrolytes. In *Progress in Polymer Science* (Vol. 81, pp. 114–143). Pergamon. https://doi.org/10.1016/j.progpolymsci.2017.12.004

Mohamad, A. A., Mohamed, N. S., Yahya, M. Z. A., Othman, R., Ramesh, S., Alias, Y., & Arof, A. K. (2003). Ionic conductivity studies of poly(vinyl alcohol) alkaline solid polymer electrolyte and its use in nickel-zinc cells. *Solid State Ionics*, *156*(1–2), 171–177. https://doi.org/10.1016/S0167-2738(02)00617-3

Mohamed, M. A., Jaafar, J., Ismail, A. F., Othman, M. H. D., & Rahman, M. A. (2017). Fourier Transform Infrared (FTIR) Spectroscopy. In *Membrane Characterization* (pp. 3–29). Elsevier Inc. https://doi.org/10.1016/B978-0-444-63776-5.00001-2

Moniha, V., Alagar, M., Selvasekarapandian, S., Sundaresan, B., & Boopathi, G. (2018). Conductive bio-polymer electrolyte iota-carrageenan with ammonium nitrate for application in electrochemical devices. *Journal of Non-Crystalline Solids*, *481*, 424–434. https://doi.org/10.1016/j.jnoncrysol.2017.11.027

Moniha, V., Alagar, M., Selvasekarapandian, S., Sundaresan, B., & Hemalatha, R. (2019). Development and characterization of bio-polymer electrolyte iota-carrageenan with ammonium salt for electrochemical application. *Materials Today: Proceedings*, *8*, 449–455. https://doi.org/10.1016/j.matpr.2019.02.135

Moniha, V., Alagar, M., Selvasekarapandian, S., Sundaresan, B., Hemalatha, R., & Boopathi, G. (2018). Synthesis and characterization of bio-polymer electrolyte based on iota-carrageenan with ammonium thiocyanate and its applications. *Journal of Solid State Electrochemistry*, *22*(10), 3209–3223. https://doi.org/10.1007/s10008-018-4028-6

Muchakayala, R., Song, S., Gao, S., Wang, X., & Fan, Y. (2017). Structure and ion transport in an ethylene carbonate-modified biodegradable gel polymer electrolyte. *Polymer Testing*, *58*, 116–125. https://doi.org/10.1016/j.polymertesting.2016.12.014

Mustafa, M. S., Ghareeb, H. O., Aziz, S. B., Brza, M. A., Al-zangana, S., Hadi, J. M., & Kadir, M. F. Z. (2020). Electrochemical characteristics of glycerolized PEO-based polymer electrolytes. *Membranes*, *10*(6), 1–16. https://doi.org/10.3390/membranes10060116

Naachiyar, R. M., Ragam, M., Selvasekarapandian, S., Krishna, M. V., & Buvaneshwari, P. (2021). Development of biopolymer electrolyte membrane using Gellan gum biopolymer incorporated with $NH_4SCN$ for electro-chemical application. *Ionics*, *27*(8), 3415–3429. https://doi.org/10.1007/s11581-021-04095-w

Noor, N. A. M., & Isa, M. I. N. (2019). Investigation on transport and thermal studies of solid polymer electrolyte based on carboxymethyl cellulose doped ammonium thiocyanate for potential application in electrochemical devices. *International Journal of Hydrogen Energy*, *44*(16), 8298–8306. https://doi.org/10.1016/j.ijhydene.2019.02.062

Pandi, D., Selvasekarapandian, S., & Bhuvaneswari, R. (2016). Development and characterization of proton conducting polymer electrolyte based on PVA, amino acid glycine and $NH_4SCN$. *Solid State Ionics*, *298*, 15–22. https://doi.org/10.106/j.ssi.2016.10.016

Pesko, D. M., Sawhney, S., Newman, J., & Balsara, N. P. (2018). Comparing Two Electrochemical Approaches for Measuring Transference Numbers in Concentrated Electrolytes. *Journal of The Electrochemical Society*, *165*(13), A3014–A3021. https://doi.org/10.1149/2.0231813jes

Pesko, D. M., Timachova, K., Bhattacharya, R., Smith, M. C., Villaluenga, I., Newman, J., & Balsara, N. P. (2017). Negative Transference Numbers in Poly(ethylene oxide)-Based Electrolytes. *Journal of The Electrochemical Society*, *164*(11), E3569–E3575. https://doi.org/10.1149/2.0581711jes

Pożyczka, K., Marzantowicz, M., Dygas, J. R., & Krok, F. (2017). Ionic conductivity and lithium transference number of poly(ethylene oxide):LiTFSI system. *Electrochimica Acta*, *227*, 127–135. https://doi.org/10.1016/j.electacta.2016.12.172

Prabakaran, P., Manimuthu, R. P., Gurusamy, S., & Sebasthiyan, E. (2017). Plasticized polymer electrolyte membranes based on PEO/PVdF-HFP for use as an effective electrolyte in lithium-ion batteries. *Chinese Journal of Polymer Science (English Edition)*, *35*(3), 407–421. https://doi.org/10.1007/s10118-017-1906-9

Premalatha, M., Mathavan, T., Selvasekarapandian, S., Selvalakshmi, S., & Monisha, S. (2017). Incorporation of NH4Br in Tamarind Seed Polysaccharide biopolymer and its potential use in electrochemical energy storage devices. *Organic Electronics*, *50*, 418–425. https://doi.org/10.1016/j.orgel.2017.08.017

Putri, R. M., Sundari, C. D. D., Floweri, O., Mayangsari, T. R., Ivansyah, A. L., Santosa, S. P., Arcana, I. M., & Iskandar, F. (2021). PEO/PVA/LiOH Solid Polymer Electrolyte Prepared via Ultrasound-assisted Solution Cast Method. *Journal of Non-Crystalline Solids*, *556*, 120549. https://doi.org/10.1016/j.jnoncrysol.2020.120549

Rajeswari, N., Selvasekarapandian, S., Karthikeyan, S., Sanjeeviraja, C., Iwai, Y., & Kawamura, J. (2013). Structural, vibrational, thermal, and electrical properties of PVA/PVP biodegradable polymer blend electrolyte with $CH_3COONH_4$. *Ionics*, *19*(8), 1105–1113. https://doi.org/10.1007/s11581-012-0838-1

Rani, M. S. A., Ahmad, A., & Mohamed, N. S. (2018). A comprehensive investigation on electrical characterization and ionic transport properties of cellulose derivative from kenaf fibre-based biopolymer electrolytes. *Polymer Bulletin*, *75*(11), 5061–5074. https://doi.org/10.1007/s00289-018-2320-3

Rasali, N. M. J., Nagao, Y., & Samsudin, A. S. (2019). Enhancement on amorphous phase in solid biopolymer electrolyte based alginate doped $NH_4NO_3$. *Ionics*, *25*(2), 641–654. https://doi.org/10.1007/s11581-018-2667-3

Rathore, M., & Dalvi, A. (2019). Electrical Characterization of PVA-$MgSO_4$ and PVA-$Li_2SO_4$ Polymer Salt Composite Electrolytes. *Materials Today: Proceedings*, *10*, 106–111. https://doi.org/10.1016/j.matpr.2019.02.195

Rayung, M., Aung, M. M., Azhar, S. C., Abdullah, L. C., Su'ait, M. S., Ahmad, A., & Jamil, S. N. A. M. (2020). Bio-based polymer electrolytes for electrochemical devices: Insight into the ionic conductivity performance. In *Materials* (Vol. 13, Issue 4). https://doi.org/10.3390/ma13040838

Ren, W., Ding, C., Fu, X., & Huang, Y. (2021). Advanced gel polymer electrolytes for safe and durable lithium metal batteries: Challenges, strategies, and perspectives. In *Energy Storage Materials* (Vol. 34, pp. 515–535). Elsevier. https://doi.org/10.1016/j.ensm.2020.10.018

Röchow, E. T., Coeler, M., Pospiech, D., Kobsch, O., Mechtaeva, E., Vogel, R., Voit, B., Nikolowski, K., & Wolter, M. (2020). In situ preparation of crosslinked polymer electrolytes for lithium ion batteries: A comparison of monomer systems. *Polymers*, *12*(8), 1707. https://doi.org/10.3390/POLYM12081707

Saadiah, M. A., Kufian, M. Z., Misnon, I. I., & Samsudin, A. S. (2021). Electrochemical Properties of CMC–PVA Polymer Blend Electrolyte for Solid State Electric Double Layer Capacitors. *Journal of Electronic Materials*, *50*(1), 303–313. https://doi.org/10.1007/s11664-020-08547-3

Saadiah, M. A., Nagao, Y., & Samsudin, A. S. (2020). Proton (H+) transport properties of CMC–PVA blended polymer solid electrolyte doped with $NH_4NO_3$. *International Journal of Hydrogen Energy*, *45*(29), 14880–14896. https://doi.org/10.1016/j.ijhydene.2020.03.213

Saadiah, M. A., & Samsudin, A. S. (2018a). Study on ionic conduction of solid bio-polymer hybrid electrolytes based carboxymethyl cellulose (CMC)/polyvinyl alcohol (PVA) doped NH4NO3. *AIP Conference Proceedings*, *2030*(Cmc). https://doi.org/10.1063/1.5066864

Saadiah, M. A., & Samsudin, A. S. (2018b). Electrical study on Carboxymethyl Cellulose-Polyvinyl alcohol based bio-polymer blend electrolytes. *IOP Conference Series: Materials Science and Engineering*, *342*(1). https://doi.org/10.1088/1757-899X/342/1/012045

Saadiah, M. A., Zhang, D., Nagao, Y., Muzakir, S. K., & Samsudin, A. S. (2019). Reducing crystallinity on thin film based CMC/PVA hybrid polymer for application as a host in polymer electrolytes. *Journal of Non-Crystalline Solids*, *511*(November 2018), 201–211. https://doi.org/10.1016/j.jnoncrysol.2018.11.032

Salman, Y. A. K., Abdullah, O. G., Hanna, R. R., & Aziz, S. B. (2018). Conductivity and electrical properties of chitosan - methylcellulose blend biopolymer electrolyte incorporated with lithium tetrafluoroborate. *International Journal of Electrochemical Science*, *13*(4), 3185–3199. https://doi.org/10.20964/2018.04.25

Sampathkumar, L., Christopher Selvin, P., Selvasekarapandian, S., Perumal, P., Chitra, R., & Muthukrishnan, M. (2019). Synthesis and characterization of biopolymer electrolyte based on tamarind seed polysaccharide, lithium perchlorate and ethylene carbonate for electrochemical applications. *Ionics*, *25*(3), 1067–1082. https://doi.org/10.1007/s11581-

019-02857-1

Samsudin, A. S., & Saadiah, M. A. (2018). Ionic conduction study of enhanced amorphous solid bio-polymer electrolytes based carboxymethyl cellulose doped $NH_4Br$. *Journal of Non-Crystalline Solids*, *497*, 19–29. https://doi.org/10.1016/j.jnoncrysol.2018.05.027

Sangeetha, M., Mallikarjun, A., Aparna, Y., Reddy, M. V., Kumar, J. S., Sreekanth, T., & Reddy, M. J. (2021). Dielectric studies and AC conductivity of PVDF-HFP: $LiBF_4$: EC plasticized polymer electrolytes. *Materials Today: Proceedings*, *44*, 2168–2172. https://doi.org/10.1016/j.matpr.2020.12.280

Selvalakshmi, S., Mathavan, T., Selvasekarapandian, S., & Premalatha, M. (2017). Study on $NH_4I$ composition effect in agar–agar-based biopolymer electrolyte. *Ionics*. https://doi.org/10.1007/s11581-016-1952-2

Selvalakshmi, S., Vijaya, N., Selvasekarapandian, S., & Premalatha, M. (2017). Biopolymer agar-agar doped with $NH_4SCN$ as solid polymer electrolyte for electrochemical cell application. *Journal of Applied Polymer Science*, *134*(15), 1–10. https://doi.org/10.1002/app.44702

Shah, D. B., Nguyen, H. Q., Grundy, L. S., Olson, K. R., Mecham, S. J., Desimone, J. M., & Balsara, N. P. (2019). Difference between approximate and rigorously measured transference numbers in fluorinated electrolytes. *Physical Chemistry Chemical Physics*, *21*(15), 7857–7866. https://doi.org/10.1039/c9cp00216b

Shanmuga Priya, S., Karthika, M., Selvasekarapandian, S., & Manjuladevi, R. (2018). Preparation and characterization of polymer electrolyte based on biopolymer I-Carrageenan with magnesium nitrate. *Solid State Ionics*, *327*(October), 136–149. https://doi.org/10.1016/j.ssi.2018.10.031

Shen, T., Zhou, H., Xin, J., Fan, Q., Yang, Z., Wang, J., Mei, T., Wang, X., Wang, N., & Li, J. (2019). Controllable microstructure of polymer-small molecule blend thin films for high-performance organic field-effect transistors. *Applied Surface Science*, *498*, 143822. https://doi.org/10.1016/j.apsusc.2019.143822

Shenbagavalli, S., Muthuvinayagam, M., & Revathy, M. S. (2022). Preparation and characterization of proton ($H^+$) conducting solid blend polymer electrolytes based on PEO/P(VdF-HFP) incorporated with $NH_4SCN$. *Journal of Non-Crystalline Solids*, *579*, 121368. https://doi.org/10.1016/j.jnoncrysol.2021.121368

Shukur, M. F., Ithnin, R., & Kadir, M. F. Z. (2014). Electrical characterization of corn starch-LiOAc electrolytes and application in electrochemical double layer capacitor. *Electrochimica Acta*, *136*, 204–216. https://doi.org/10.1016/j.electacta.2014.05.075

Shukur, M. F., & Kadir, M. F. Z. (2015). Hydrogen ion conducting starch-chitosan blend based electrolyte for application in electrochemical devices. *Electrochimica Acta*, *158*, 152–165. https://doi.org/10.1016/j.electacta.2015.01.167

Silva, M. M., Bermudez, V. D. Z., & Pawlicka, A. (2019). Insight on polymer electrolytes for electrochemical devices applications. *Polymer Electrolytes: Characterization Techniques and Energy Applications*, 113–136. https://doi.org/10.1002/9783527805457.ch5

Singh, R., Polu, A. R., Bhattacharya, B., Rhee, H. W., Varlikli, C., & Singh, P. K. (2016).

Perspectives for solid biopolymer electrolytes in dye sensitized solar cell and battery application. *Renewable and Sustainable Energy Reviews*, *65*, 1098–1117. https://doi.org/10.1016/j.rser.2016.06.026

Singla, M. K., Nijhawan, P., & Oberoi, A. S. (2021). Hydrogen fuel and fuel cell technology for cleaner future: a review. In *Environmental Science and Pollution Research* (Vol. 28, Issue 13, pp. 15607–15626). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s11356-020-12231-8

Sohaimy, M. I. H., & Isa, M. I. N. (2017). Ionic conductivity and conduction mechanism studies on cellulose based solid polymer electrolytes doped with ammonium carbonate. *Polymer Bulletin*, *74*(4), 1371–1386. https://doi.org/10.1007/s00289-016-1781-5

Sponchioni, M., Capasso Palmiero, U., & Moscatelli, D. (2019). Thermo-responsive polymers: Applications of smart materials in drug delivery and tissue engineering. In *Materials Science and Engineering C* (Vol. 102, pp. 589–605). Elsevier. https://doi.org/10.1016/j.msec.2019.04.069

Sugumaran, T., Silvaraj, D. S., Saidi, N. M., Farhana, N. K., Ramesh, S., Ramesh, K., & Ramesh, S. (2019). *The conductivity and dielectric studies of polymer electrolytes based on iota-carrageenan with sodium iodide and 1-butyl-3-methylimidazolium iodide for the dye-sensitized solar cells*. 763–771.

Sundaramahalingam, K., Muthuvinayagam, M., Nallamuthu, N., Vanitha, D., & Vahini, M. (2019). Investigations on lithium acetate-doped PVA/PVP solid polymer blend electrolytes. *Polymer Bulletin*, *76*(11), 5577–5602. https://doi.org/10.1007/s00289-018-02670-2

Swaminathan, A., Ravi, R., Sasikumar, M., Dasaiah, M., Hirankumar, G., & Ayyasamy, S. (2020). Preparation and characterization of PVA/PAM/$NH_4SCN$ polymer film by ultrasound-assisted solution casting method for application in electric double layer capacitor. *Ionics*, *26*(8), 4113–4128. https://doi.org/10.1007/s11581-020-03542-4

Trevisol, T. C., Fritz, A. R. M., de Souza, S. M. A. G. U., Bierhalz, A. C. K., & Valle, J. A. B. (2019). Alginate and carboxymethyl cellulose in monolayer and bilayer films as wound dressings: Effect of the polymer ratio. *Journal of Applied Polymer Science*, *136*(3). https://doi.org/10.1002/app.46941

Vahini, M., & Muthuvinayagam, M. (2018). AC impedance studies on proton conducting biopolymer electrolytes based on pectin. *Materials Letters*, *218*, 197–200. https://doi.org/10.1016/j.matlet.2018.02.011

Wang, Q. J., Zhang, P., Wang, B., & Fan, L. Z. (2021). A novel gel polymer electrolyte based on trimethylolpropane trimethylacrylate/ionic liquid via in situ thermal polymerization for lithium-ion batteries. *Electrochimica Acta*, *370*, 137706. https://doi.org/10.1016/j.electacta.2020.137706

Wang, Y., Song, S., Xu, C., Hu, N., Molenda, J., & Lu, L. (2019). Development of solid-state electrolytes for sodium-ion battery–A short review. *Nano Materials Science*, *1*(2), 91–100. https://doi.org/10.1016/j.nanoms.2019.02.007

Watanabe, M., Nagano, S., Sanui, K., & Ogata, N. (1988). Estimation of Li+ transport number in polymer electrolytes by the combination of complex impedance and potentiostatic polarization measurements. *Solid State Ionics*, *28–30*(PART 2), 911–917.

https://doi.org/10.1016/0167-2738(88)90303-7

Weston, J. E., & Steele, B. C. H. (1982). Effects of inert fillers on the mechanical and electrochemical properties of lithium salt-poly(ethylene oxide) polymer electrolytes. *Solid State Ionics*, *7*(1), 75–79. https://doi.org/10.1016/0167-2738(82)90072-8

Xiao, W., Wang, Z., Zhang, Y., Fang, R., Yuan, Z., Miao, C., Yan, X., & Jiang, Y. (2018). Enhanced performance of P(VDF-HFP)-based composite polymer electrolytes doped with organic-inorganic hybrid particles PMMA-ZrO2 for lithium ion batteries. *Journal of Power Sources*, *382*, 128–134. https://doi.org/10.1016/j.jpowsour.2018.02.012

Xie, Z., Wu, Z., An, X., Yoshida, A., Wang, Z., Hao, X., Abudula, A., & Guan, G. (2019). Bifunctional ionic liquid and conducting ceramic co-assisted solid polymer electrolyte membrane for quasi-solid-state lithium metal batteries. *Journal of Membrane Science*, *586*, 122–129. https://doi.org/10.1016/j.memsci.2019.05.066

Xu, Z. X., Fu, X. Q., & Wang, Q. (2016). Phase Stability of Ammonium Nitrate with Organic Potassium Salts. *Central European Journal of Energetic Materials*, *Vol. 13*(3), 736–754. https://doi.org/10.22211/CEJEM/65013

Yuan, S., Bao, J. L., Wei, J., Xia, Y., Truhlar, D. G., & Wang, Y. (2019). A versatile single-ion electrolyte with a Grotthuss-like Li conduction mechanism for dendrite-free Li metal batteries. *Energy and Environmental Science*, *12*(9), 2741–2750. https://doi.org/10.1039/c9ee01473j

Zainuddin, N. K., Rasali, N. M. J., Mazuki, N. F., Saadiah, M. A., & Samsudin, A. S. (2020). Investigation on favourable ionic conduction based on CMC-K carrageenan proton conducting hybrid solid bio-polymer electrolytes for applications in EDLC. *International Journal of Hydrogen Energy*, *45*(15), 8727–8741. https://doi.org/10.1016/j.ijhydene.2020.01.038

Zainuddin, N. K., Rasali, N. M. J., & Samsudin, A. S. (2018). Study on the effect of PEG in ionic transport for CMC-$NH_4Br$-based solid polymer electrolyte. *Ionics*, *24*(10), 3039–3052. https://doi.org/10.1007/s11581-018-2505-7

Zainuddin, N. K., Saadiah, M. A., Abdul Majeed, A. P. P., & Samsudin, A. S. (2018). Characterization on conduction properties of carboxymethyl cellulose/kappa carrageenan blend-based polymer electrolyte system. *International Journal of Polymer Analysis and Characterization*, *23*(4), 321–330. https://doi.org/10.1080/1023666X.2018.1446887

Zainuddin, N. K., & Samsudin, A. S. (2018a). Investigation on the effect of NH4Br at transport properties in k–carrageenan based biopolymer electrolytes via structural and electrical analysis. *Materials Today Communications*, *14*, 199–209. https://doi.org/10.1016/j.mtcomm.2018.01.004

Zainuddin, N. K., & Samsudin, A. S. (2018b). Electrical properties studies of solid polymer electrolytes membrane based on carboxymethyl cellulose (CMC)/kappa carrageenan blend. *AIP Conference Proceedings*, *2030*. https://doi.org/10.1063/1.5066863

Zhang, X., Xie, J., Shi, F., Lin, D., Liu, Y., Liu, W., Pei, A., Gong, Y., Wang, H., Liu, K., Xiang, Y., & Cui, Y. (2018). Vertically Aligned and Continuous Nanoscale Ceramic-Polymer Interfaces in Composite Solid Polymer Electrolytes for Enhanced Ionic Conductivity. *Nano Letters*, *18*(6), 3829–3838. https://doi.org/10.1021/acs.nanolett.8b01111

Zhang, Y., Zheng, Z., Liu, X., Chi, M., & Wang, Y. (2019). Fundamental Relationship of Microstructure and Ionic Conductivity of Amorphous LLTO as Solid Electrolyte Material. *Journal of The Electrochemical Society*, *166*(4), A515–A520. https://doi.org/10.1149/2.0161904jes

Zhao, L., Fu, J., Du, Z., Jia, X., Qu, Y., Yu, F., Du, J., & Chen, Y. (2020). High-strength and flexible cellulose/PEG based gel polymer electrolyte with high performance for lithium ion batteries. *Journal of Membrane Science*, *593*, 117428. https://doi.org/10.1016/j.memsci.2019.117428

Zhu, J., Zhang, Z., Zhao, S., Westover, A. S., Belharouak, I., & Cao, P. F. (2021). Single-Ion Conducting Polymer Electrolytes for Solid-State Lithium–Metal Batteries: Design, Performance, and Challenges. In *Advanced Energy Materials* (Vol. 11, Issue 14). John Wiley and Sons Inc. https://doi.org/10.1002/aenm.202003836

Zhu, Y., Cao, J., Chen, H., Yu, Q., & Li, B. (2019). High electrochemical stability of a 3D cross-linked network PEO@nano-$SiO_2$ composite polymer electrolyte for lithium metal batteries. *Journal of Materials Chemistry A*, *7*(12), 6832–6839. https://doi.org/10.1039/c9ta00560a

Zulkifli, A., Saadiah, M. A., Mazuki, N. F., & Samsudin, A. S. (2020). Characterization of an amorphous materials hybrid polymer electrolyte based on a $LiNO_3$-doped, CMC-PVA blend for application in an electrical double layer capacitor. *Materials Chemistry and Physics*, *253*, 123312. https://doi.org/10.1016/j.matchemphys.2020.123312