

# Effect of Glycerin on Electrical and Thermal properties of PVA/Copper Sulphate Gel polymer electrolytes

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## Research Article

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## Abstract

Copper-ion conducting gel polymer electrolyte (GPE) systems based on polymer poly(vinyl alcohol) (PVA) and copper sulphate salt doped with glycerin as plasticizer have been synthesized by using solution casting method. Differential scanning calorimetry is used to examine the thermal effect of glycerin on a plasticized polymer electrolyte (DSC). With the addition of various quantities of glycerin, as a plasticizer in pure PVA and PVA+20wt.%CuSO<sub>4</sub> gel polymer electrolyte shows a decrease in the values of melting temperature (54.34°C), glass transition temperature (37.22°C) and percentage of crystallinity (11.65%). Compared to pure PVA, thermal degradation measured from TGA curve for the plasticized gel electrolyte is shifted to lower temperatures and the weight loss of the polymer electrolyte increase with increase of glycerin concentration. From DTG, the temperature of maximum decomposition for PVA is 283.4 °C, and it is decreased with adding 20 wt.% CuSO<sub>4</sub> and upon increased concentration of the plasticizer from 1 to 3 mL of glycerin. For pure PVA and PVA+20wt.% CuSO<sub>4</sub>,  $\epsilon'$  decreases with increasing glycerin concentration and peaks at 3 mL glycerin concentration. The maximum ionic conductivity obtained was  $9.39 \times 10^{-4}$  S/cm for PVA+20wt.%CuSO<sub>4</sub>+3 mL glycerin.

## Introduction

In electrochemical devices, rechargeable batteries (RBs) have become an increasingly essential energy storage system [1]. The electrolyte, which allows ions to travel through to create the battery current, is a critical component of a salt-ion battery [2]. Metal salts and an organic solvent are the most common components of liquid electrolytes. However, there are several important considerations for practical applications, such as the safety of liquid electrolyte, particularly when the batteries are subjected to thermal, mechanical, or electrical abuse [3]. Gel polymer electrolytes (GPEs), which contain plasticizers such ethylene carbonate, propylene carbonate, starch, or glycerin, are being explored as a viable alternative to currently available organic liquid electrolytes [4]. Gel polymer electrolytes (GPE) are a compromise technique that offers benefits such as improved ionic conductivity at room temperature, high reliability, high flexibility, no leakage, and good performance [5]. Polyethylene oxide (PEO) and polyvinyl alcohol (PVA), are examples of polymer matrixes [6]. In GPEs, the liquid electrolyte is immobilized in a polymeric matrix, which may reduce the risk of leakage as compared to commercial separators.

GPEs are a type of polymer electrolyte that combines the advantages of liquid and solid components in one package. GPEs have attracted a lot of attention as a dual nature function of electrolytes [6, 7]. Combining heterogeneous (phase-separated) and homogeneous (uniform) gels results in high ionic conductivity and good interfacial characteristics in the liquid phase, as well as superior mechanical qualities in the solid phase [8]. The majority of GPEs exhibit a remarkable ionic conductivity on the order of  $10^{-3}$  S/cm at ambient temperature [9]. In general, the polymer framework with metal ion transport occurs in the swelling gelled phase or liquid phase for heterogeneous GPEs, which can support the electrochemical performance of the battery cell involving GPEs [10].

PVA (polyvinyl alcohol) is a synthetic biodegradable polymer. It has a high dielectric constant, is inexpensive, and is non-toxic. It's recognized for its capacity to form films and chemical stability, as well as its ability to retain sticky properties and functional (OH) groups with a high-density chemical cross-linking potential [6]. Plasticizers, composite addition, polymer blending, and in-situ polymerization techniques to lower the crystallinity of the resultant matrix as a result of higher chain flexibility of the polymeric backbone have all been utilized to improve the conductivity of PVA-based polymer electrolytes [11]. If copper ion conducting polymer electrolytes with no discernible electronic conductivities are discovered, they could be used in solid polymer batteries. As an anode material in solid state batteries, copper has various benefits over metallic lithium. Copper is more environmentally friendly and less expensive than metallic lithium [12].

Plasticizers change the characteristics of PVA films, such as water sorption, mechanical properties, and glass transition temperature. Glycerin is used as a plasticizer to produce polymer gel electrolyte films. Glycerin melts and flows at temperatures ranging from 90 to 180°C [11]. The purpose of this initiative was to generate fresh concepts. PVA gel polymer electrolyte using 20% CuSO<sub>4</sub> and glycerin as plasticizers. The impact of glycerin ratio on crystallinity, thermal stability, and ionic conductivity of produced films was also examined.

## Experimental Details

### Materials

Poly(vinyl alcohol) (PVA) as a white powder with molecular weight (14,000 g/mol) produced by Sigma-Aldrich, USA, ionic conductor Copper sulphate (CuSO<sub>4</sub>) powder with molecular weight (159,609 g/mol) (from Sigma-Aldrich, USA and glycerin (HOCH<sub>2</sub>CH(OH)CH<sub>2</sub>HO) as a liquid plasticizer with density (1.26 g/cm<sup>3</sup>) received from India.

# Preparation of pure PVA and gel PVA films

The solution cast process was used to make gel polymer electrolyte samples. PVA (molecular weight of 14,000) was used as the polymer. CuSO<sub>4</sub> was added accordingly. Distilled water was employed as the solvent in this experiment. To get a homogenous solution, the mixture was agitated at room temperature for up to 10 hours. After adding the needed amount of glycerin as a plasticizer, the solution was suspended and agitated for roughly 4 hours. These solution mixtures were then poured into glass petri dishes and dried for 72 hours, resulting in a thick film with thickness about ~ 65µm that was peeled off and stored in desiccators to dry further. The composition used for making gel polymer electrolytes is shown in Table 1.

## Characterization

The glass transition temperature was measured using a Differential Scanning Calorimeter (DSC) powered by Mettler- Toledo/USA over a temperature range of 40 to 90°C, and thermal stability was measured using a thermogravimetric analyzer (TGA-DTG) under N<sub>2</sub> gas and heating at a rate of 10°C/min powered by Mettler- Toledo/USA over a temperature range of 25 to 300°C. The resistivities were measured at room temperature using GWINSTEK LCR-6100 with a frequency range of 1–100 kHz.

Table 1  
Compositions of the pure PVA and PVA/CuSO<sub>4</sub>/Glycerin electrolyte films.

Sample	PVA Weight (in gm)	CuSO <sub>4</sub> Weight (in gm)	Amount of Glycerin
Pure PVA	0.8	0	0
PVA/20 wt.%CuSO <sub>4</sub>	0.64	0.16	0
PVA/20 wt.% CuSO <sub>4</sub> /1 mL glycerin	0.64	0.16	1 mL
PVA/20 wt.% CuSO <sub>4</sub> /2 mL glycerin	0.64	0.16	2 mL
PVA/20 wt.% CuSO <sub>4</sub> /3 mL glycerin	0.64	0.16	3 mL

## Results And Discussion

### Thermal Analysis

The thermal effect of glycerin on a plasticized polymer electrolyte is investigated using differential scanning calorimetry (DSC). In Fig. 1, the DSC curves of pure PVA, PVA + 20wt% CuSO<sub>4</sub>, and PVA + 20wt% CuSO<sub>4</sub> plasticized by 1, 2 and 3 mL glycerin are presented. An endothermic peak corresponding to the melting temperature (T<sub>m</sub>) and the glass transition temperature (T<sub>g</sub>) of pure PVA is discovered at 73.12°C and 66.02°C, respectively. When 20 wt% of CuSO<sub>4</sub> salt was added to the polymer matrix, the melting temperature (T<sub>m</sub>), glass transition temperature (T<sub>g</sub>), and degree of crystallinity (χ<sub>c</sub>) were all increased.

The glass transition temperature (T<sub>g</sub>) moved towards the lower temperature side when different amounts of glycerin were added to the prepared electrolyte membrane PVA + 20wt% CuSO<sub>4</sub> polymer electrolyte. The decrease in T<sub>g</sub> of the polymer electrolyte with increased glycerin content suggests a weaker intermolecular connection between the glycerin, CuSO<sub>4</sub> salt, and PVA, allowing the polymer network to move more segmentally by making the polymer matrix more flexible [12, 13]. Glycerin's plasticizing action produces a reduction in the T<sub>m</sub> and T<sub>g</sub> of polymer gel electrolyte membranes when it is added. The degree of crystallinity (χ<sub>c</sub>) and melting temperature increased when 20 wt% of CuSO<sub>4</sub> salt was added to the polymer matrix (T<sub>m</sub>) were initially elevated, but this increased crystallinity and melting temperature was successfully controlled by the addition of glycerin and achieved the lowest value (approximately 11.65%) for the membrane contains a higher amount of glycerin (3mL).

The DSC parameters are presented in Table 2. The relative percentage of crystallinity (χ<sub>c</sub>) has been calculated with the Eq. (1).

$$\chi = \frac{\Delta H_f}{\Delta H_{fo}} \times 100 \dots \dots \dots (1)$$

Where  $\Delta H_{f0} = 2.65$  (J/g). The calculated heat of fusion ( $H_f$ ), melting temperature ( $T_m$ ), and percentage crystallinity ( $\chi_c$ ) values are shown in Table 2.

Table 2  
DSC parameters of pure PVA, PVA + 20wt.% of  $\text{CuSO}_4$  and PVA + 20wt.% of  $\text{CuSO}_4$  plasticized by 1, 2 and 3 mL of glycerin.

samples	Melting temperature (°C)	Glass transition temperature (°C)	$\Delta H_f$ (J/g)	percentage of crystallinity ( $\chi_c$ %)
Pure PVA	73.12	66.02	85.23	32.12
PVA + 20wt.% $\text{CuSO}_4$	74.24	67.34	87.34	32.95
PVA + 20wt.% $\text{CuSO}_4$ /1 mL glycerin	64.78	53.12	50.12	18.91
PVA + 20wt.% $\text{CuSO}_4$ /2 mL glycerin	59.89	42.62	34.22	12.91
PVA + 20wt.% $\text{CuSO}_4$ /3 mL glycerin	54.34	37.22	30.89	11.65

The heat of fusion ( $H_f$ ), melting temperature ( $T_m$ ), and percentage of crystallinity all decreased when plasticized with 1, 2 and 3 mL of glycerin. This is owing to a decrease in PVA polymer electrolyte crystallinity, which is a well-known favorable condition for boosting ionic conductivity.

TGA thermographs of pure PVA, PVA + 20 wt%  $\text{CuSO}_4$ , and PVA + 20 wt%  $\text{CuSO}_4$  plasticized by 1, 2, and 3 mL glycerin gel polymer electrolytes are shown in Fig. 2. The plot clearly shows two stages of weight loss, the first of which is a 5% weight loss at 54.3 °C and the second of which is a maximum weight loss at 285.8 °C for pure PVA and PVA + 20 wt%  $\text{CuSO}_4$ , both of which can be attributed to evaporation of water and degradation of PVA by the polymer chain's dehydration reaction [13]. Water absorption, heat degradation of functional groups, and thermal oxidation of the polymer backbone are the processes in which the PVA + 20wt%  $\text{CuSO}_4$ /Glycerin gel polymer electrolyte loses weight [14].

All membranes lose weight before reaching 50 °C in the first phase, which can be attributed to the evaporation of bound water in the samples. The release of the quaternary ammonium group's degraded product causes weight loss in the second phase in the range 124 to 180 °C [12]. Weight loss in the third phase at 200–230 °C is assumed to be caused by the release of residual quaternary ammonium group. At 270–300 °C, the fourth and final weight loss was discovered, which was caused by polymer chain breakdown [12, 14].

The weight loss of the polymer electrolyte increases as the glycerin concentration rises, which is due to scission monomers and bonds in the polymeric backbone cracking and loss of dopant due to heat energy [15]. The decomposition of organic polymer chains, both the hard segment of PVA linkage and the soft segment from glycerin, was attributed to the decomposition of plasticizer with polymer [14, 16].

The DTG thermograms of pure PVA, PVA + 20wt%  $\text{CuSO}_4$ , and PVA + 20wt%  $\text{CuSO}_4$  plasticized by 1, 2, and 3 mL glycerin are shown in Fig. 3. The maximal decomposition temperature of PVA is 283.4 °C, and this temperature drops when 20 wt% of  $\text{CuSO}_4$  is added and the plasticizer concentration is increased from 1 to 3 mL. For PVA + 20 wt.%  $\text{CuSO}_4$  had a  $T_{max}$  of 272°C, which dropped to 261°C for the electrolyte PVA + 20 wt.%  $\text{CuSO}_4$ /3mL glycerin. This phenomenon has been linked to the low Tg value of the plasticized gel polymer electrolyte. The dipole-dipole interaction of polymer chains was reduced when glycerin was added, because it softens the polymer chain's backbone and lowers the polymer's Tg. The same pattern was found by Abdulkadir et al., 2020 [17].

Figure 4 shows the results of separating  $\text{CuSO}_4$  salt to cations and anions in PVA GPE. The GPEs were created by injecting conducting salt ( $\text{CuSO}_4$ ) into the polymer host (PVA) and plasticizing it with glycerin, as described in the experimental section. PVA and glycerin with hydroxyl or polar groups (-OH) produced a covalent dative bond with the  $\text{CuSO}_4$  cations in the electrolytes [17, 18]. This is because polymer materials (PVA) and plasticizers (glycerin) have -OH groups in their macromolecular chains and three-dimensional networks that can react with various inorganic salts [19, 20]. The presence of polar -OH groups enable chemical (complexing processes) and physical connections (via H bonding, Van der Waals dipole-ion interactions, or dipole-dipole interactions) [21].  $\text{CuSO}_4$  dissociates into cations ( $\text{Cu}^{+2}$ ) and anions ( $\text{SO}_4^{-2}$ ) when dissolved in solvent is shown in Eq. 2.



The cations formed when coordination with the polar groups (-OH) of the plasticized polymer matrix, resulting in a complex molecule, as shown in Fig. 4. Because of the interaction between the plasticized polymer polar groups and the cations from the salts, there are more ion-conducting sites and a better interfacial contact, resulting in a higher ionic conductivity for the electrolyte [19, 22]. Metal ions from salts interact with each other and polar groups (-OH) of polymers by electrostatic interactions, resulting in the formation of coordinating bonds [17, 23]. The type of functional groups attached to the polymer backbone, their compositions and distances between them, molecular weight, branching degree, metal cation nature and charge, and counter ions are all important factors that might affect polymer-metal ion interactions [20, 24].

The dielectric constant decreases with increasing frequency and reaches a stable value at high frequencies (100 kHz), as shown in Figs. 5 and 6. A rapid decline in dielectric constant can be seen throughout a frequency range of 1 to 100 kHz, because the charge carriers do not have enough time to orient themselves in the field direction. The periodic reversal of the field occurs so quickly at very high frequencies, resulting in the frequency-independent  $\epsilon'$  behaviour observed [21, 25]. The ions are capable of migrating in the direction of the electric field, but due to the blocking electrodes in the low frequency area, they are unable to reach the external circuit, resulting in a dispersion with large  $\epsilon'$  values. As a result, ions become trapped along the electrode-electrolyte contact, forming an electrode polarization layer [22, 26]. This indicates that electrode polarization and space charge effects are dominant in the low frequency region.

The dielectric constant of the system increases when 20 wt%  $\text{CuSO}_4$  is added to pure PVA. This could be due to a high dielectric constant combined with a strong dissociation capacity to avoid the formation of ion pairs or a high efficiency in shielding the interionic coulombic attraction between cations and anions, resulting in a high dielectric constant [23, 27].

The effect of glycerin concentration on  $\epsilon'$  of the gel polymer electrolytes was investigated in the frequency range from 1 to 100 kHz is shown in Figs. 5 and 6. The dielectric constant  $\epsilon'$  decrease with increasing glycerin content for pure PVA and PVA + 20wt.%  $\text{CuSO}_4$  in the above frequency range. 5 and 6. It achieves a high value at 3 mL glycerin concentration. This type of behaviour has also been observed in electrical conductivity investigations (see Table 3). The decrease in  $\epsilon'$  is due to a reduction in mobile charge carrier density. The addition of plasticizer to the polymer salt system introduces additional ions, lowering the density of charge carriers and thereby lowering the gel polymer electrolyte system's dielectric constant [21].

We can see from Table 3 that when pure PVA and PVA + 20wt.%  $\text{CuSO}_4$  are exposed to an electric field, the cations from the salts can migrate from one coordinated site to another. This is due to the weak coordinates of the cations with sites along the polymer chain [16]. According to prior research [21], ions, primarily cations, connected to functional groups of the host polymer chains can move along the polymer backbone by recoordination. After that, the polymer chains are folded to form tunnels in which the functional groups locate and coordinate the cations. Cations can readily flow via these tunnels, which form channels [14, 23].

Conducting salts have also been found to reduce the number of active centers in polymer chains, diminishing intermolecular and intramolecular interactions [14]. As a result, the stiffness of the host polymer will be lowered, and the mechanical and thermomechanical properties of the polymer will be altered [18, 23]. Similarly, introducing high conducting salts reduces the glass transition temperature ( $T_g$ ) of the polymer system (as would be stated in DSC data) [14, 28]. As a result, crystallinity will decrease and salt dissociation capacity will increase, resulting in enhanced charge carrier transport and greater ionic conductivity [22, 28].

An increase in glycerin concentration, which results in the formation of a complex between the polymer matrix and the conducting salt (PVA +  $\text{CuSO}_4$ ), would raise entropy, which will improve the composite's segmental motion. Reduced crystallinity (greater flexibility) and enhanced electrolyte ionic conductivity will result from increased segmental motion [23, 30].

Table 3  
ionic conductivity of pure PVA, PVA + 20wt.%CuSO<sub>4</sub> and PVA + 20wt.%CuSO<sub>4</sub> plasticized by 1, 2 and 3 mL glycerin.

Ionic conductivity (S/cm)	Frequency (kHz)	Pure PVA				PVA + 20wt.%CuSO <sub>4</sub>			
		0 mL glycerin	1 mL glycerin	2 mL glycerin	3 mL glycerin	0 mL glycerin	1 mL glycerin	2 mL glycerin	3 mL glycerin
	1	7.43×10 <sup>-4</sup>	3.48×10 <sup>-4</sup>	5.46×10 <sup>-4</sup>	1.83×10 <sup>-4</sup>	1.38×10 <sup>-4</sup>	2.02×10 <sup>-4</sup>	2.24×10 <sup>-4</sup>	1.57×10 <sup>-4</sup>
	10	3.39×10 <sup>-4</sup>	4.68×10 <sup>-4</sup>	7.87×10 <sup>-4</sup>	2.31×10 <sup>-4</sup>	1.17×10 <sup>-4</sup>	3.93×10 <sup>-4</sup>	4.54×10 <sup>-4</sup>	4.95×10 <sup>-4</sup>
	20	6.48×10 <sup>-4</sup>	4.87×10 <sup>-4</sup>	8.48×10 <sup>-4</sup>	2.42×10 <sup>-4</sup>	2.27×10 <sup>-4</sup>	4.55×10 <sup>-4</sup>	5.48×10 <sup>-4</sup>	6.25×10 <sup>-4</sup>
	30	1.01×10 <sup>-4</sup>	4.98×10 <sup>-4</sup>	8.77×10 <sup>-4</sup>	2.48×10 <sup>-4</sup>	3.59×10 <sup>-4</sup>	4.94×10 <sup>-4</sup>	5.92×10 <sup>-4</sup>	7.08×10 <sup>-4</sup>
	40	1.16×10 <sup>-4</sup>	5.07×10 <sup>-4</sup>	8.96×10 <sup>-4</sup>	2.53×10 <sup>-4</sup>	4.66×10 <sup>-4</sup>	5.21×10 <sup>-4</sup>	6.31×10 <sup>-4</sup>	7.68×10 <sup>-4</sup>
	50	1.29×10 <sup>-4</sup>	5.16×10 <sup>-4</sup>	9.09×10 <sup>-4</sup>	2.57×10 <sup>-4</sup>	5.67×10 <sup>-4</sup>	5.42×10 <sup>-4</sup>	6.61×10 <sup>-4</sup>	8.14×10 <sup>-4</sup>
	60	1.40×10 <sup>-4</sup>	5.25×10 <sup>-4</sup>	9.19×10 <sup>-4</sup>	2.60×10 <sup>-4</sup>	6.57×10 <sup>-4</sup>	5.58×10 <sup>-4</sup>	6.86×10 <sup>-4</sup>	8.49×10 <sup>-4</sup>
	70	1.48×10 <sup>-4</sup>	5.33×10 <sup>-4</sup>	9.28×10 <sup>-4</sup>	2.63×10 <sup>-4</sup>	7.41×10 <sup>-4</sup>	5.72×10 <sup>-4</sup>	7.07×10 <sup>-4</sup>	8.77×10 <sup>-4</sup>
	80	1.56×10 <sup>-4</sup>	5.42×10 <sup>-4</sup>	9.36×10 <sup>-4</sup>	2.66×10 <sup>-4</sup>	8.17×10 <sup>-4</sup>	5.84×10 <sup>-4</sup>	7.24×10 <sup>-4</sup>	9.01×10 <sup>-4</sup>
	90	1.62×10 <sup>-4</sup>	5.51×10 <sup>-4</sup>	9.42×10 <sup>-4</sup>	2.68×10 <sup>-4</sup>	8.86×10 <sup>-4</sup>	5.95×10 <sup>-4</sup>	7.39×10 <sup>-4</sup>	9.21×10 <sup>-4</sup>
	100	1.68×10 <sup>-4</sup>	5.60×10 <sup>-4</sup>	9.48×10 <sup>-4</sup>	2.70×10 <sup>-4</sup>	9.51×10 <sup>-4</sup>	6.04×10 <sup>-4</sup>	7.53×10 <sup>-4</sup>	9.39×10 <sup>-4</sup>

## Conclusion

In this work, plasticized gel polymer electrolytes based on PVA + 20wt% CuSO<sub>4</sub> have been produced with great flexibility, low glass transition temperature, low dielectric constant, and strong ionic conductivity. The glass transition temperature (T<sub>g</sub>) of the generated membranes altered to the lower temperature side with the addition of varied amounts of glycerin as a plasticizer in pure PVA and PVA + 20wt.% CuSO<sub>4</sub> gel polymer electrolyte. When compared to pure PVA, the plasticized gel electrolyte's thermal breakdown is transferred to lower temperatures, and the weight loss of the polymer electrolyte increases as the glycerin content increases. By adding 1, 2 and 3 mL of glycerin as a plasticizer to a PVA + 20wt.% CuSO<sub>4</sub> film, the conductivity can be increased to the order of 10<sup>-4</sup> S/cm. There are more ion-conducting sites and a better interfacial interaction because of the connection between the plasticized polymer polar groups and the cations from the salts (Cu<sup>2+</sup>), resulting in a higher ionic conductivity for the electrolyte. These results suggested that, this would be suitable separator for rechargeable batteries.

## References

1. S. B. Aziz, T. J. Woo, M. F. Z. Kadir, H. M. Ahmed, "A Conceptual Review on Polymer Electrolytes and Ion Transport Models", *Journal of Science: Advanced Materials and Devices*, vol.3, pp.1-17, (2018).
2. S. Çavus, E. Durgun, "Poly(vinyl alcohol) Based Polymer Gel Electrolytes: Investigation on Their Conductivity and Characterization", *Acta physica polonica A*, vol. 129, pp. 121-124, (2016).
3. Sh. Shi, X. Peng, T. Liu, Y. Chen, Ch. He, H. Wang, "Facile preparation of hydrogen-bonded supramolecular polyvinyl alcohol-glycerol gels with excellent hermoplasticity and mechanical properties", *Polymer*, Vol. 111, pp. 168-176, (2017).
4. H. Zhai, P. Xu, M. Ning, Q. Cheng, J. Mandal, Y. Yang, A Flexible Solid Composite Electrolyte with Vertically Aligned and Connected Ion-Conducting Nanoparticles for Lithium Batteries. *Nano Letters*, vol.17, pp.3182-3187, (2017).
5. Y. Wang, W. Zhong, Development of Electrolytes towards Achieving Safe and High- Performance Energy- Storage Devices: A Review. *Chem Electro Chem*, vol. 2, pp.22-36, (2015).
6. A. A. Kareem, "Thermal and Electrical Properties of Polyimide/PANI Nanofiber Composites Prepared Via in Situ Polymerization", *Material Science Poland*, vol. 36, pp.283–287, (2018).
7. Ch. Wen, Y. Chen, Ch. Wang, Ch. Peng, Sh. Lin, K. Huang, "Properties of a gel polymer electrolyte based on lithium salt with poly(vinyl butyral)", *Ionics*, vol. 24, pp.1385–1389, (2018).
8. L. Long, S. Wang, M. Xiao, Y. Meng, "Polymer Electrolytes for Lithium Polymer Batteries", *J. Mater. Chem. A Mater, Energy Sustain*, vol. 4, pp.10038–10069, (2016).

9. Sh. M. Abdelcareem, M. K. Jawad, "Investigate salts type and concentration on the conductivity of polymer electrolyte", *Iraqi Journal of Physics*, Vol.17, PP. 42-50, (2019).
10. Sh. Peng, Sh. Liu, Y. Sun, N. Xiang, X. Jiang, L.i Hou, " Facile preparation and characterization of poly(vinyl alcohol)-NaCl-glycerol supramolecular hydrogel electrolyte", *European Polymer Journal*, Vol. 106, pp. 206–213, (2018).
11. S. Patachia, M. Rinja, L. Isac, "Some Methods for Doping Poly (Vinyl Alcohol) Hydrogels [Pva-hg]", *Romanian Journal of Physics*, vol. 51, pp.253–262, (2006).
12. K. Perera, M.A.K.L. Dissanayake, P.W.S.K. Bandaranayake, "Copper-ion conducting solid-polymer electrolytes based on polyacrylonitrile (PAN) ", *Electrochimica Acta*, vol.45 pp.1361–1369, (2000).
13. M. Mohsin, A. Hossin, Y. Haik, "Thermal and Mechanical Properties of Poly(vinyl alcohol) Plasticized with Glycerol", *Journal of Applied Polymer Science*, vol. 122, pp.3102–3109 (2011).
14. S. L. Agrawal, A. Awadhia, " DSC and conductivity studies on PVA based proton conducting gel electrolytes", *Bulletin of Material Science*, vol. 27, pp. 523–527, (2004).
15. G. Ayala, A. Agudelo, R. Vargas, "Effect of glycerol on the electrical properties and phase behavior of cassava starch biopolymers", *Dyna*, vol. 79, pp. 138-147, (2012).
16. J. Tarique, S. M. Sapuan, A. Khalina, "Effect of glycerol plasticizer loading on the physical, mechanical, thermal, and barrier properties of arrowroot (*Maranta arundinacea*) starch biopolymers", *Scientific Reports*, vol. 11, pp.1-17, (2021).
17. B. A. Abdulkadir, J. O. Dennis, M. F. Bin, A. Shukur, M. M. Elsayed, F. Usman, "Preparation and characterization of gel polymer electrolyte based on PVA-K<sub>2</sub>CO<sub>3</sub>", *Polymer-Plastics Technology and Materials*, vol. 59, pp.1679-1697, (2020).
18. S. Chaurasia, M. Singh, M. K. Singh, P. Kumar, A. L. Saroj, " Impact of ionic liquid incorporation on ionic transport and dielectric properties of PEO-lithium salt-based quasi-solid-state electrolytes: role of ion-pairing", *Journal of Materials Science: Materials in Electronics*, DOI: 10.1007/s10854-022-07706-y, (2022).
19. A. Arya, A. L. Sharma, Effect of salt concentration on dielectric properties of Li-ion conducting blend polymer electrolytes. *Journal of Materials Science: Materials in Electronics.*, vol. 29, pp.17903-17920, (2018).
20. M. F. Z. Kadir, S. R. Majid, A. K. Arof, "Plasticized chitosan-PVA blend polymer electrolyte based proton battery", *Electrochim Acta*, vol.55, pp.1475–1482, (2010).
21. R. I. Mattos, C. E. Tambelli, E. Raphael, I. D. A. Silva, C. J. Magon, J. P. Donoso, A. Pawlicka, "Proton mobility and copper coordination in polysaccharide and gelatin-based bioblends and polyblends", *Cellulose*, vol.21, pp.2247–2259, (2014).
22. A. Gupta, A. Jain, S. K. Tripathi, "Structural, electrical and electrochemical studies of ionic liquid-based polymer gel electrolyte using magnesium salt for supercapacitor application", *Journal of Polymer Research*, Vol.28, pp.1-11, (2021).
23. G. Hirankumar, N. Mehta, "Effect of incorporation of different plasticizers on structural and ion transport properties of PVA-LiClO<sub>4</sub> based electrolytes", *Heliyon*, Vol. 4, pp.1-26, (2018).
24. E. A. Swady, M. K. Jawad, " Study FTIR and AC Conductivity of Nanocomposite Electrolytes", *Iraqi Journal of Physics*, Vol.19, PP.15-22, (2021).
25. A. Pawlicka, M. Danczuk, W. Wieczorek, E. Zygadło-Monikowska, "Influence of Plasticizer Type on the Properties of Polymer Electrolytes Based on Chitosan", *Journal of Physical Chemistry A*, vol.112, pp.8888–8895, (2008).
26. N. J. H. Almashhadani, "UV-Exposure effect on the mechanical properties of PEO/PVA blends", *Iraqi Journal of Science*, vol. 62, pp. 1879-1892, (2021).
27. H. Kh. Rasheed and A. A. Kareem, "The Potential Barrier and Thermal Stability Dependence on PI Thickness of Al/PI/c-Si Schottky Diode", *Iraqi Journal of Science*, vol. 61, pp. 3235-3241, (2020).
28. H. Kh. Rasheed and A. A. Kareem, " Effect of Multiwalled Carbon Nanotube Reinforcement on the Opto-Electronic Properties of Polyaniline/c-Si Heterojunction", *Journal of Optical Communications*, vol.42, pp. 25–29, (2021).
29. T. Maheshwari, K. Tamilarasan, S. Selvasekarapandian, R. Chitra, S. Kiruthika, "Investigation of blend biopolymer electrolytes based on Dextran-PVA with ammonium thiocyanate", *Journal of Solid State Electrochemistry* vol. 25, pp. 755–765 (2021).
30. N. M. Ali, A. A. Kareem, " Ionic conductivity enhancement for PVA/ 20wt.% CuSO<sub>4</sub> gel polymer electrolyte by using glycerin", *Chalcogenide Letters*, Vol. 19, pp. 217 – 225, (2022).

## Figures

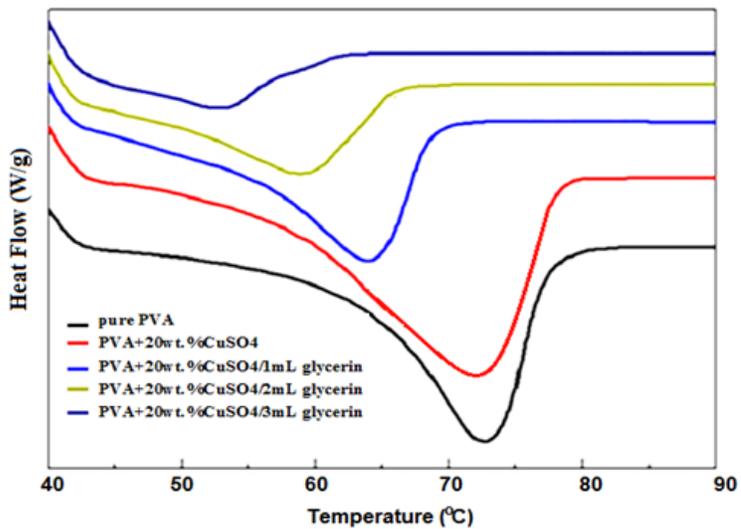


Figure 1

DSC curves of pure PVA, PVA+20wt.% CuSO<sub>4</sub> and PVA+20wt.% CuSO<sub>4</sub> plasticized with 1, 2 and 3 mL of glycerin.

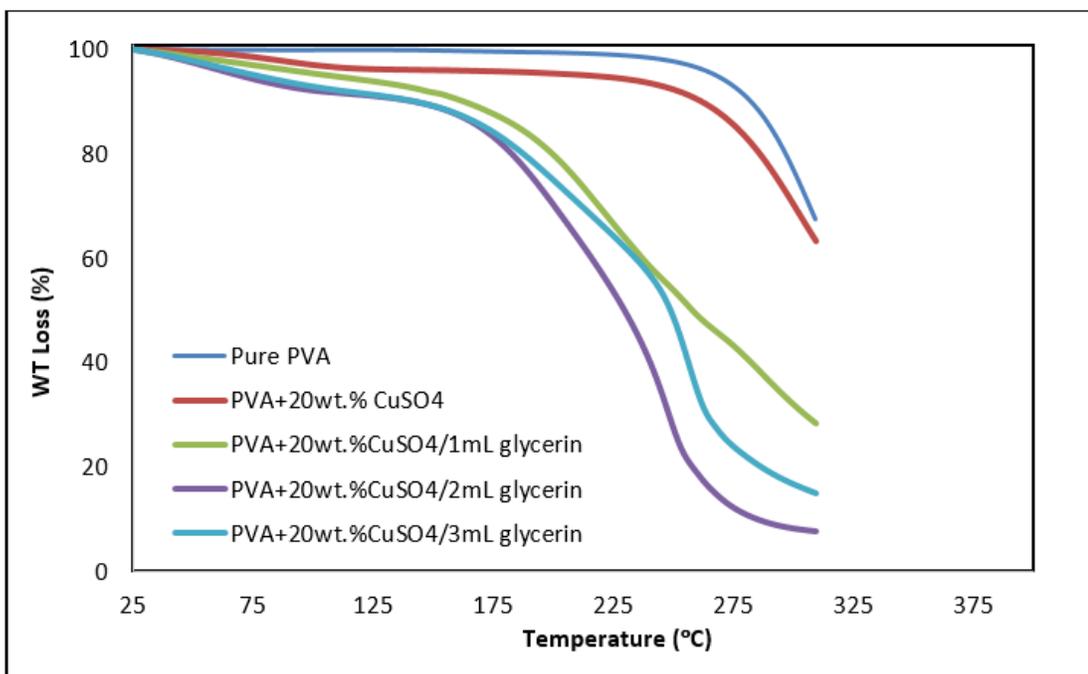


Figure 2

TGA thermograph of pure PVA, PVA+20wt.% CuSO<sub>4</sub> and PVA+20wt.% CuSO<sub>4</sub> plasticized by 1, 2 and 3 mL glycerin gel polymer electrolytes.

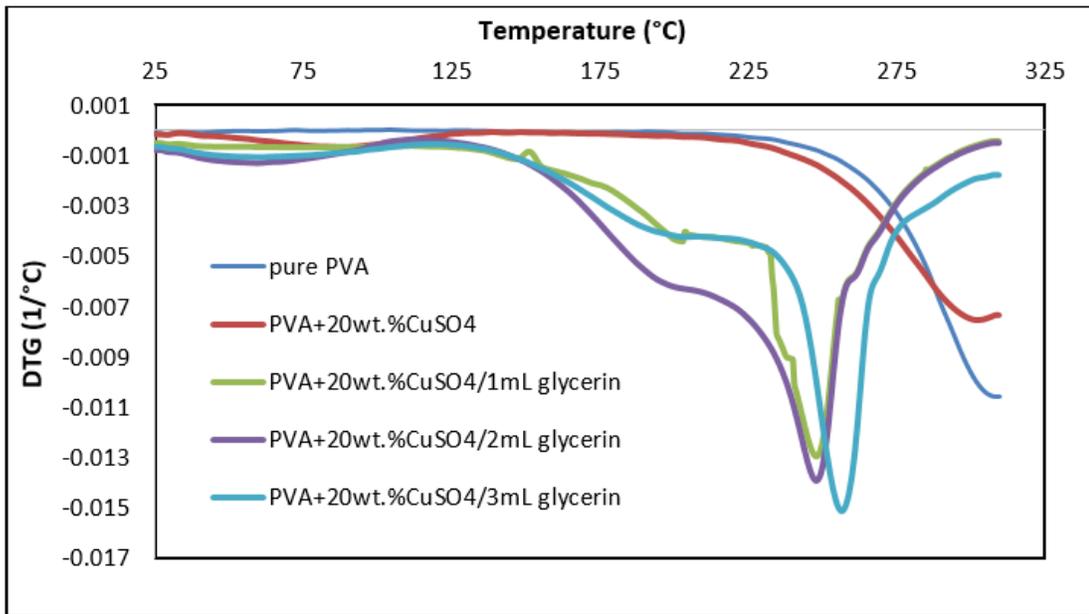


Figure 3

DTG thermograms of pure PVA, PVA+20wt.%CuSO<sub>4</sub> and PVA+20wt.%CuSO<sub>4</sub> plasticized by 1, 2 and 3 mL glycerin.

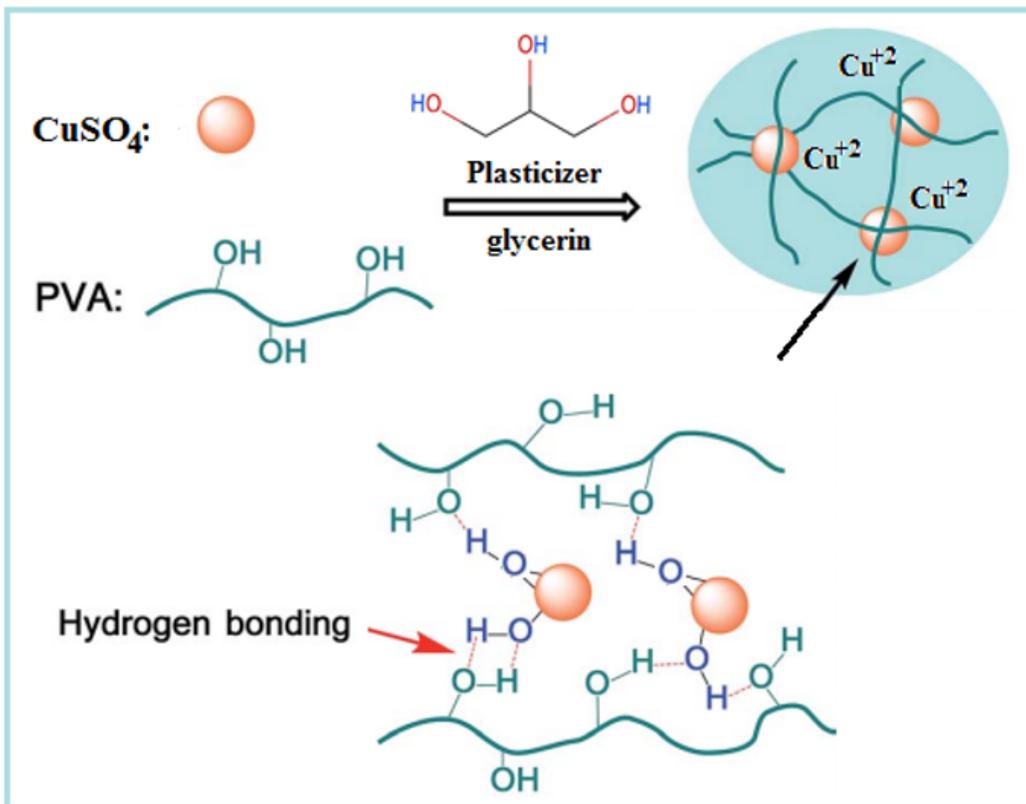


Figure 4

Structure analysis of glycerin plasticized PVA+ CuSO<sub>4</sub> GPE.

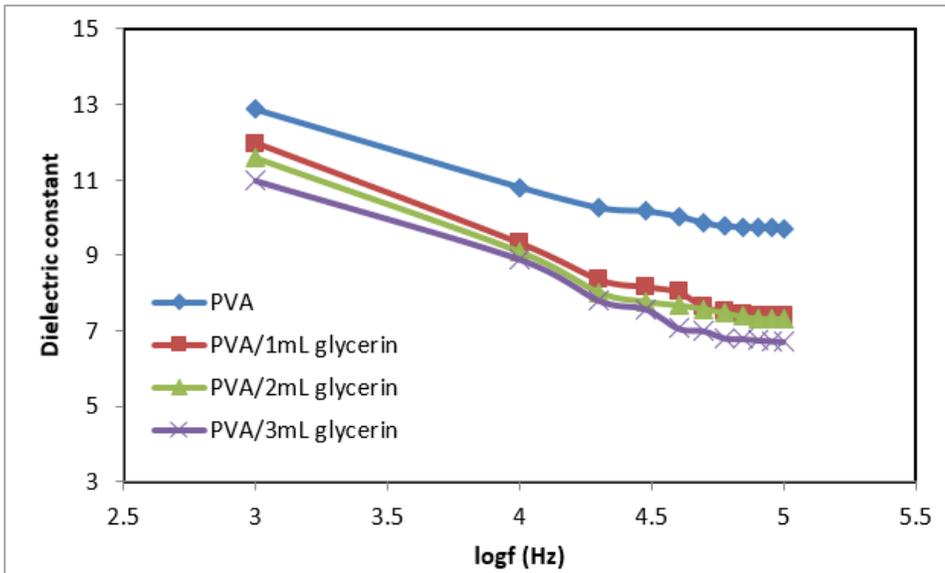


Figure 5

Frequency dependence of dielectric constant ( $\epsilon'$ ) for the pure PVA, plasticized with 1, 2 and 3 mL glycerin.

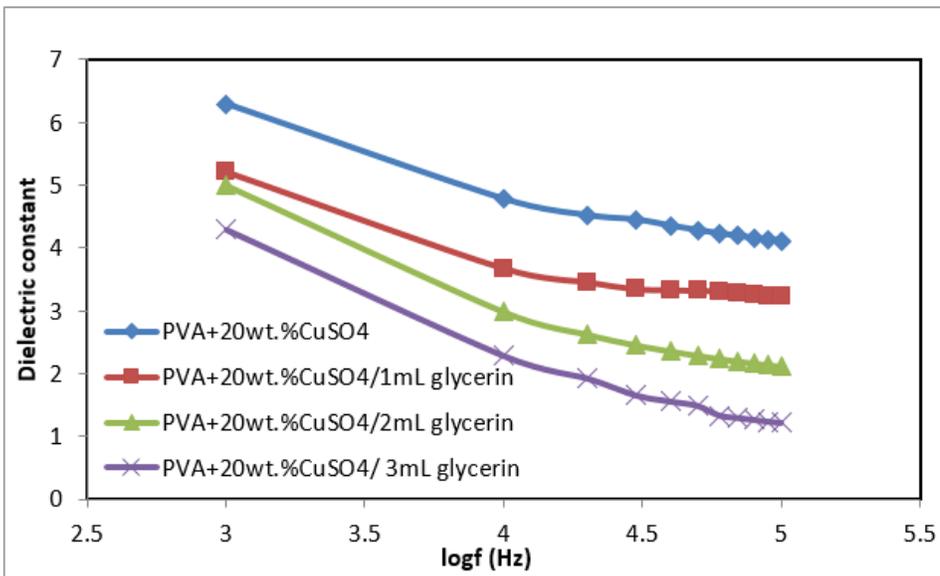


Figure 6

Frequency dependence of dielectric constant ( $\epsilon'$ ) for the PVA+20wt.%  $\text{CuSO}_4$  gel polymer electrolyte plasticized with 1, 2 and 3 mL glycerin.