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Polymer Based Optoelectronics in Clinical Application Treated with Sodium Fluoride and Aqueous Dimethyl Sulfoxide Solutions

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Abstract

In polymer science, dimethyl sulfoxide (DMSO) and sodium fluoride (NaF) are frequently combined to dissolve, modify, or treat particular polymers, most notably in the processing of cellulose and the creation of polyvinylidene fluoride (PVDF) membranes. The viscosities, ultrasonic velocities, and sodium fluoride densities of aqueous solutions of dimethyl sulfoxide (DMSO) have been measured at T=303.15, 308.15, 313.15, and 318.15 K. Fluorides (such as NaF or TBAF) help break inter-chain hydrogen bonds to improve polymer solubility or alter crystal structures. This information has been used to compute the apparent molal volumes (Vφ), apparent molal compressibilities (Kφ), and viscosity A and B-coefficients of different combinations. This density values were used to compute the standard partial molal volumes (ΔVφ0) and standard partial molal volumes of transfer (Vφ0). The effects of sodium fluoride, Optoelectronic polymers are useful substances that have coupled-electron systems that allow for flexible, lightweight, and solution-processable devices, such as PEDOT:PSS, P3HT, and PPV. Their tunable bandgaps, high conductivity (up to S/cm), and superior transparency make them indispensable for OLEDs, organic solar cells (OSCs), and sensors. The advancements and uses of polymer materials in optoelectronics are thoroughly covered in this article. In particular, the exciton–vibrational coupling, nonradiative and radiative processes. In medical field optoelectronics are uses in cancer detection, minimally invasive surgery (endoscopy), non-invasive, real-time vital sign monitoring (heart rate, pulse oximetry), and vision restoration by retinal implants.

Keywords: B-coefficient for viscosity, Partial molal volume, Partial molal compressibility, Sodium fluoride, and dimethyl sulfoxide.

INTRODUCTION

Polymeric materials have expanded at an unprecedented rate, mostly as a result of advances in material design synthesis and purification methods. Particularly since the mid-1900s, when ground-breaking discoveries like the generation of conducting materials and electroluminescence in molecular crystals were established, this fundamental research has been essential in driving important technological advancements. [2] This finding brought organic materials into the spotlight, highlighting their vast potential for electrical applications and opening the door for additional technological advancements. Additionally, the interdisciplinary character of organic optoelectronics, which includes fields like chemistry, physics, materials science, and engineering, has promoted a collaborative research environment.

This mixing of several fields has not only fostered creativity but also made it possible to create novel materials and gadgets with previously unheard-of capabilities. For instance, the use of organic materials in electronics has resulted in eco-

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friendly, flexible, and lightweight alternatives to conventional silicon-based electronics. This multidisciplinary approach has been crucial in developing the subject and broadening the range of possible uses, especially with regard to the synthesis-based tunability of organic materials.

Electrolytes that dissolve in water are classified as either structure makers or structure breakers based on the charge density. Reports state that although ions with a high charge density behave in the opposite way and form net structures, those with a low charge density disturb them. [5] It is fascinating to investigate the ionic processes associated with the solution of powerful electrolytes. Electrolytes disrupt the molecular structure of bulk water when dissolved in it due to the strong electric field of the constituent ion solvents in aqueous solutions, including electrolyte experimental viscosities are necessary for the design of processes involving mass transfer, fluid movement, etc., and they also provide details about the structure of liquids.

Dental decay is treated with sodium fluoride (NaF), a colorless crystalline salt. It is known that DMSO (CH3)2SO) is a dipolar aprotic solvent that tends to create associations through interactions between dipoles. DMSO is known to enhance penetration into the epidermis The behavior of salts in DMSO aqueous solutions has received less attention than the thermodynamic properties of different solutes in single and mixed solvents.

LITERATURE REVIEW

Mercerized cellulose from sisal and cotton linters was carboxymethylated using the novel cellulose solvent dimethyl sulfoxide (DMSO)/tetrabutylammonium fluoride (TBAF) as a reaction medium. The molar ratio of the reagent and NaOH to anhydroglucose unit (AGU) and the addition of the NaOH as solid particles or an aqueous solution were the reaction parameters that were investigated. Exclusion of Size The dissolution media and/or derivatizing technique used in the current work cause a specific depolymerization on the cellulose chains, according to chromatography results (SEC). Following acidic depolymerization of the carboxymethylcellulose (CMC), 1H NMR spectroscopy and HPLC were used to study the pattern of substitution within [1] the AGU and throughout the polymer chains of the CMC. The sequence of substitution is O-6>O-2≥O-3.

Cellulose can be effectively dissolved and derivatized using solutions of certain quaternary ammonium fluoride hydrates in dimethyl sulfoxide (DMSO). The hydrated fluorides of the quaternary ammonium ions dibenzyldimethyl (BMAF-0.1H2O), [2] tetraallyl (TAAF-H2O), and tetra(1-butyl) (TBAF-3H2O) are some examples. Cellulose is not dissolved by the tetramethyl compound (TMAF). Here, we describe the synthesis of industrially significant cellulose ethers, such as allyl-, benzyl-, and sodium carboxymethyl cellulose, using a solution of (BMAF-0.1H2O) in DMSO in the presence of dispersed solid NaOH. of the reactant halides and the generated cellulose ethers, as well as the decreased activity of the NaOH-bound water.

Dimethyl sulfoxide is a dipolar aprotic solvent with a high polarity, a powerful electron donor, and liquidity across a broad temperature range. [3] As a result, it is a great and selective solvent for a variety of organic and even polymeric compounds, and it can form dipole-dipole associations and H-bonds. Dimethyl sulfoxide's structure, which consists of a "soft" sulfur atom and a "hard" oxygen atom, results in poor anion solvation and good cation solvation. As a result, alkoxide mixtures with dimethyl sulfoxide are among the most highly basic systems in organic chemistry. They work very well for eliminations, the start of polymerizations, and the deprotonation of weakly acidic OH, NH, and CH bonds.

Acrylonitrile (AN) and sodium p-styrenesulfonate (SSS) copolymerization in dimethyl sulfoxide solution has been studied. The monomer reactivity ratios for AN and SSS at 45°C are $r1 = 0.15 \pm 0.02$ and $r2 = 0.55 \pm 0.03$. Price Q and e values for SSS of 0.44 and −0.38, respectively, are computed from these data. [4] Because various solvents have different electron distributions, the values are observed to differ from those in aqueous solutions. Copolymerization rates at 45°C at first. Copolymerization rates in the range of 90–95 mole% SSS in the monomer feed are caused by the coexistence of liquids with different optical densities.

Nuclear magnetic resonance (NMR) was used to examine cellulose solutions in a mixture of tetrabutylammonium fluoride and dimethyl sulfoxide (TBAF/DMSO) with tiny and varied volumes of water. [5] The dissolution and gelation mechanisms for cellulose in TBAF/DMSO were clarified by examining the composition dependences of 19F NMR and 1H NMR chemical shifts and line widths. According to our findings, the extremely electronegative fluoride ions function as hydrogen bond acceptors to cellulose hydroxyl groups, breaking cellulose-cellulose hydrogen bonds and giving the chains an effective negative charge, which dissolves the polymer.

Graphene's exceptional qualities have rekindled interest in inorganic, two-dimensional materials with distinctive optical and electrical characteristics. Strong in-plane bonding and mild out-of-plane interactions allow transition metal dichalcogenides [6] (TMDCs) to exfoliate into two-dimensional layers with a single unit cell thickness. Despite decades of research on TMDCs, fresh developments in the characterization of nanoscale materials and the creation of devices have created new possibilities for two-dimensional layers of thin TMDCs in optoelectronics and nanoelectronics. TMDCs like MoS2, MoSe2, WS2, and WSe2 have large bandgaps that shift from indirect to direct in single layers, opening up possibilities for future developments in optoelectronics and electronics as well as applications like transistors.

A type of hybrid materials known as metal-organic frameworks (MOFs) have special optical and electrical characteristics that result from the organic linkers and metal ions/clusters rationally self-assembling to provide a wide variety of potential structural motifs. Many research groups are investigating the possibility of using MOFs as active components [7] in devices like solar cells, photodetectors, radiation detectors, and chemical sensors due to their order, chemical tunability, and good environmental stability. The current state of MOF research in the areas of electrical, opto-electronic, and sensor devices is summarized by numerous new fundamental insights that are pertinent to the integration required to construct MOF-based devices, even though this subject is still in its early stages.

Discotic liquid crystals (DLCs) are advantageous because to their long-range self-assembling, self-healing, processing ease, solubility in a variety of organic solvents, and high charge-carrier mobilities along the stacking axis have been used in opto-electronic devices. This article provides an overview of DLCs,[8] including their alignment, theoretical modeling, charge-carrier mobilities, and device applications. The impact of alignment on DLCs' charge-carrier characteristics is examined. Processing methods such as zone-casting, zone melting, Langmuir-Blodgett deposition, solution-casting on preoriented polytetrafluoroethylene (PTFE), surface treatment, IR irradiation, application of a magnetic field, use of sacrificial layers, use of blends, application of an electric field, and others that achieve appropriate alignment of DLCs for effective electronic devices are given special attention.

Molecular units are generated independently and then arranged into various condensed phases to create molecular materials. By their very nature, the physicochemical properties of the isolated molecular units (symmetry, polarity, redox potentials, absorption spectrum) can be used to infer the optical properties (polarizability and hyperpolarizability) and[9] electrical properties (ferro- and antifemlectricity, semiconductivity) of the molecular materials. Columnar and nematic lenticular mesophases are produced by octaalkyl-phthalocyanine derivatives. It has been demonstrated that these liquid crystalline phases can be used in the fields of electronics, opto-electronics, and iono-electronics.

Originally created to mimic graphene, graphene oxide (GO) was quickly acknowledged as a functional material in and of itself, filling a gap in the application space that graphene and other carbon materials cannot.[10] Research on GO has advanced significantly in material synthesis and property tailoring over the last ten years. As a result, GO-based photonics, electronics, and optoelectronics have advanced quickly, opening the door for remarkable technological advancements. optical communications, picture display, and medical diagnosis. We also go over the difficulties in this area as well as the promising prospects for further technical developments.

The discovery and production of new families of engineering materials known as polymers over the past 150 years has challenged traditional materials and enabled the development of new products that have expanded humanity's range of activities. [11] The history of the most significant categories of polymeric materials, including plastics, fibers, and elastomers, is briefly reviewed in this paper. Plastics have led the way in the development of polymeric materials during the past 150 years, followed by fibers and elastomers.

Enamel and dentin specimens (n = 10, for each substrate) were used to test solutions in an erosion-remineralization cycle model. The negative control was distilled water. The cycle comprised 120 minutes of human saliva immersion, 5 minutes in a 0.3% citric acid solution, and 120 minutes of human saliva exposure, four times a day, for five days. [12] Solutions (pH = 4.5) were used for two minutes, twice a day. Optical profilometry was used to assess surface loss (SL). After the hydroxyapatite crystals were treated with the solutions, their zeta potential was measured. A statistical analysis was performed on the data ($\alpha = 0.05$).For both substrates, all fluoride solutions showed noticeably lower SL values than the control.

Because of their low cost, light weight, electrical, mechanical, and optical qualities, composite materials are utilized in a wide range of applications, including solar cells, elements, light emitting diodes (LED), optoelectronic devices, and industrial uses [13] in the automotive, military, and aerospace industries. The synthesis of PS-PMMA copolymer has been studied in this work. Sodium fluoride was added to PS-PMMA copolymer at weight percentages of (0,1,2,3).

The casting technique was used to prepare the samples. composites' optical characteristics in the 200–800 nm wavelength range. The findings demonstrated that as the concentration of sodium fluoride increased, the PS-PMMA copolymer's absorption coefficient, extinction coefficient, refractive index, and real and imaginary dielectric constants all increased.

Using the solution casting approach, biopolymer electrolytes based on a combination of cornstarch and polyvinyl pyrrolidone with varying weight percentages of sodium fluoride salt were created. X-ray diffraction measurements were used to examine the amorphous nature of the polymer blend with the addition of NaF. Fourier Transformation. [14] The existence of functional groups and the complicated development between the bonding of polymer chains were found through infrared research. The dielectric behavior was measured at different temperature ranges (303–373 K) and frequencies (1 Hz–1 MHz) using an AC impedance analyzer. As the temperature and salt content increased, the ionic conductivity improved. The relaxing process was examined using an argond plot. Cyclic voltammetry was used to verify electrochemical stability.

In order to achieve good sodium-ion conductivity at room temperature, gel polymer electrolyte (GPE) films were produced utilizing a polyvinylidene fluoride–hexafluoropropylene (PVdF–HFP) matrix. Microporous PVDF-HFP membranes filled and swelled in various liquid electrolytes produced GPE of PVF-HFP: GPEs were created by filling and swelling microporous PVDF-HFP membranes with various liquid electrolytes [15], such as ionic liquids (1-ethyl-3-methylimidazolium bis (trifluoromethanesulfonyl) imide and 1-butyl-3-methyl bis (trifluoromethane sulfonylimide) or carbonate solvents (propylene carbonate (PC), fluoroethylene carbonate (FEC). TGPEs have a "sponge-like" structure with large pore sizes and a high porosity of 80–85%. At normal temperature, GPEs' ionic conductivity was 1-2 mS.cm−1. GPEs were used as conduction media for the coin-cell type sodium

This study examines how adding Na and F ions to a glass ionomer cement that does not naturally contain those ions [16] affects the cement's interactions with a diluted (0.2%) NaF solution. It is necessary to look into how the solution affects the cement's surface morphology as well as how the cement affects the solution in terms of absorbing Na+ and F− and changing pH. These findings should be contrasted with earlier findings from glasses that contained one, both, or neither of the ions.

The solubility parameter was used to describe the physical characteristics of the polyacrylonitrile (PAN) solutions in N, N-dimethyl formamide (DMF) and dimethyl sulfoxide (DMSO). Individual solubility parameters, especially the polar term, [17] were more important in determining the physical qualities than the total solubility parameter. The dynamic viscosity (η′) of concentrated solutions increased with temperature, while the intrinsic viscosity and hydrodynamic diameter of diluted solutions declined. These effects were more noticeable with DMF than with DMSO; DMF produced higher η′ and yield stress. DMSO produced a cocontinuous structure while DMF produced a scattered morphology when the polymer solutions were dried at 25 °C.

By selectively oxidizing poly (ethylene sulfide), poly (ethylene sulfoxide) with about 100% sulfinyl groups in the main chain was created. Anionic ring-opening polymerization of ethylene sulfide produced poly (ethylene sulfide), which was then reacted in an HNO_3/CH_3SO_3H system at 0 °C for 24 hours to produce poly (ethylene sulfoxide) in a quantifiable yield. 1H NMR, 13C NMR, and IR spectra verified the polysulfoxide's structure. [18] When the reaction was carried out at room temperature, the polymer including sulfoxide and sulfone units was produced because a shorter reaction time resulted in insufficient oxidation. temperature. It was discovered that poly (ethylene sulfoxide) and poly (vinyl alcohol) were miscible. These findings demonstrate that poly (ethylene sulfoxide), an aprotic polar solvent, has the repeating structure of dimethyl sulfoxide. Styrene and methyl methacrylate have been polymerized using dimethyl sulfoxide as a solvent. In solvent-monomer mixes of different compositions,[19] the chain-transfer coefficients of the solvent and the values of δ [i.e., (2kt)1/2/kp] were found. In the case of styrene, δ was found to be constant, whereas in the case of methyl methacrylate, it was found to be depending on the solvent content. In the instance of methyl methacrylate, the decrease in δ values with increasing solvent concentration has been explained by an interaction between the solvent and poly (methyl methacrylate) radical, which lowers the termination rate.

Applications of Li-air batteries (LABs) at below-freezing temperatures are thought to be negatively impacted by the electrolyte's instability and inadequate ionic conductivity. In this work, high donor number dimethyl sulfoxide (DMSO) is confined within an in situ polymerized 4,4′-bis(stearoylamino)diphenyl ether [20] (BSDE) matrix to create a polymer-constrained gel (PCG) electrolyte appropriate for low-temperature LABs. Strong hydrogen interactions between the DMSO molecules and the BSDE framework have broken DMSO's frozen structure, improving ionic conductivity at lower temperatures. Additionally, the Li salt is dissolved using DMSO as a solvent to provide a local high-concentration electrolyte.

POLYMER ANALYSIS

Polymer materials constitute a vibrant and promising field within materials science. Through molecular design and chemical synthesis, these materials' tunable electronic and optical properties can be precisely adjusted, enabling researchers to control crucial parameters like energy levels, bandgaps, and charge carrier mobility for particular technological needs. The conductivity of polymer materials varies greatly, ranging from semiconductors to insulators, and in certain situations, it even approaches that of metals. Because of their prolonged π-conjugation and absence of free charge carriers, traditional polymer materials are usually insulators with very low electrical conductivity. The mobility of polymer chains often increases with temperature, resulting in increased ductility and flexibility but possibly decreased strength. Polymers may experience phase changes, such as glass transition or melting, at high temperatures, which may have an impact on their mechanical and thermal stability. On the other hand, polymers may become brittle and more prone to fracture at low temperatures.

ELECTRONIC CHARACTERISTIC OF POLYMER

Light Absorption

Polymers' ability to absorb light is essential to their use in a variety of optoelectronic applications, such as light-emitting diodes (LEDs) and organic photovoltaics (OPVs). The interaction between electronic excitations (excitons) and the molecule's vibrational modes frequently results in complex patterns in the optical absorption spectra of polymer molecules. [8] C–C stretching and C–H wagging in benzene rings are two examples of these vibrational modes. The absorption characteristics are greatly influenced by the interaction between these modes.

Coupling by Vibration

A polymer molecule changes from its ground state to its excited state upon absorbing a photon. This process includes vibrational excitations in addition to electronic transitions. The Franck-Condon principle Fig 1. which stipulates that the strength of an absorption line is proportional to the overlap integral of the vibrational wavefunctions of the ground and excited states, quantifies the coupling between electronic and vibrational states. [6] The Franck-Condon factor, which is the square of the overlap integral of the vibrational wavefunctions, describes the likelihood of an electronic transition that also includes vibrational excitement. In terms of mathematics, this factor affects the absorption cross-section and, thus, the intensity of the spectrum's absorption peak

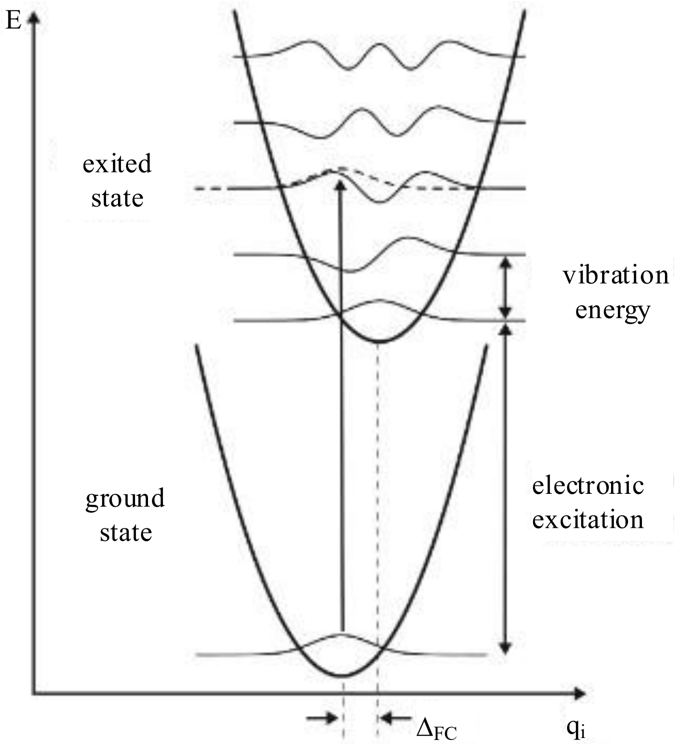

Figure 1. ~~Light absorption with vibrational coupling.~~

Electronic transitions between a ground state and an excited state take place according to the light absorption principle. By integrating over the electronic transition dipole moment μ and the vibrational overlap integrals, one may describe the absorption coefficient α(ω) of a polymer.

$$\alpha(\omega) \propto \in_{i\,f\,(\omega i-\omega f)\,\delta(Et-Et-hw)} \tag{1}$$

where δ is the Dirac delta function that ensures energy conservation ωi and ωf are the initial and final vibronic states, respectively. [9] This formula emphasizes how the absorption coefficient depends on both the vibrational structure and the electronic transition dipole moment.

Light Emission

A polymer goes through a number of relaxation steps to return to its ground state after absorbing a photon. Radiative and nonradiative [10] paths can be used to broadly classify these activities. Applications in optoelectronic devices like organic light-emitting diodes (OLEDs) require an understanding of these principles.

Non Radiative Process

The dissipation of energy through non-light-emitting means, such as heat, collisions, and molecular conformational changes, is known as nonradiative relaxation [12] Thermal vibrations are the result of excess energy being transferred to the surrounding lattice or medium, which causes energy dissipation as heat. In collisions, molecules contact with one another, transferring energy and promoting relaxation. The efficiency of light emission in polymers can be greatly impacted by these activities, which compete with radiative pathways.

Radiative Process

Photons are released during radiative relaxation, which increases the material's output of visible light. The primary radiative processes are fluorescence, phosphorescence, and delayed fluorescence, as seen in Fig 2.

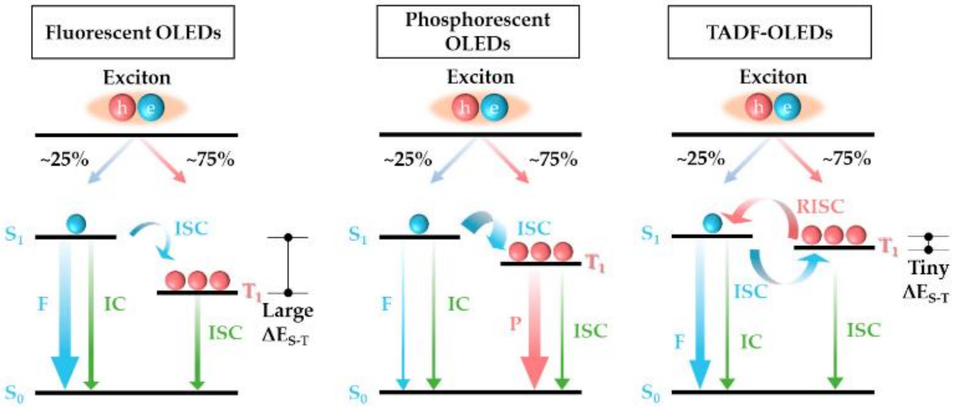

Figure 2. Radiative process

The operating principles of fluorescence, phosphorescence, [12] and thermally activated delayed fluorescence.

TREATING POLYMER IN DMSO AND SODIUM FLUORIDE

Sodium fluoride (99% assay S.D. Fine Chem Ltd., Mumbai) was used without any pre-treatment. After being kept on molecular sieves (Type 0.4nm Merck Ltd., Mumbai), dimethyl sulfoxide was used without further purification. Double-distilled deionized water with a conductivity of 1.5×10-4 Ω-1·m-1 was used to create aqueous DMSO solutions. [9] These solutions were then utilized as solvents to make sodium fluoride solutions at concentrations of 0.05, 0.1, 0.15, and 0.2 M. A graded stem with a 5×10-7 dm3 division and a pyrex glass single stem pycnometer with a bulb capacity of 12×10-3 dm3 were used to measure the densities of the solutions). Each measurement was performed three times, and the average results are displayed. The repeatability values for density, viscosity, and ultrasonic speed are ±2.8 × 10-4 g.±cm-3, ±0.03%, and ±2 × 10-3 mPa·s, in that orderWith an inaccuracy of ± 0.01K, the samples' temperature was maintained within an electrically controlled thermostatic water bath during the measurements. The specifics of the experimental procedures have already been published elsewhere.

Polymers are dissolved in DMSO (typically at high temperatures, such as 50–120°C), the mixture is cast onto a substrate, and the solvent is eliminated by total evaporation in an oven at about 85°C, or by creating thin films with a doctor blade process. Using solvents like acetone, sodium fluoride can be mixed with polymer hosts such as polyethylene oxide (PEO) or polymethyl methacrylate (PMMA). [15] Sustained release is made possible by the inclusion of PEO, a water-soluble polymer that aids in dispersing NaF clusters throughout the polymer bulk. The ultrasonic speed was measured at a frequency of 2 MHz using a multifrequency ultrasonic interferometer.

RESULTS AND DISCUSSION

The observed densities are transformed into apparent molal volumes (Vφ) using the following formula

$$V\varphi = \frac{M}{\rho} - 1000\frac{(\rho - \rho 0)}{m\,\rho\,\rho 0} \quad (2)$$

The molar mass and molality of sodium fluoride are represented by the letters M and m, respectively. The solvent and solution densities are denoted by the symbols ρ and ρ0, respectively.

The density (ρ) experimental measurements for various sodium fluoride molal compositions in aqueous DMSO solution are provided in Table 1

Sodium fluoride molal volume values at T=303.15, 308.15, 313.15, and 318.15 K. Vφ values can be fitted using the equation

$$V\varphi = V\varphi\,0 + Sv.\,m \quad (3)$$

Table 1. Calculative density of DMIF and DMSO.

Compounds	Experimental Density gm/cm^3		Theoretical Density gm/cm^3
	DMF	DMSO	
IM-01	1.2513	1.1637	1.2018
IM-02	1.1444	1.1660	1.2170
IM-03	1.1275	1.1596	1.2018
IM-04	1.1673	1.1786	1.1849
IM-05	1.2285	1.1410	1.2472
IM-06	1.2794	1.1827	1.2578
IM-07	1.2226	1.1801	1.1952
IM-08	1.1174	1.1700	1.2559
IM-09	1.1853	1.1680	1.2667

The partial molal volume can be thought of as equal to the limiting values of the apparent molal volume, Vφ0. Sv is the slope that illustrates solute-to-solute interactions caused by solute concentration effects.

The values of Vφ0 and Sv are evaluated using Vφ with m. On the other hand, when Vφ does not show a linear relationship with m, Vφ0 is calculated by averaging all of the data point. This case, Vφ0 and Sv are evaluated and the findings are shown in Table 2.

Table 2. Findings of sodium fluoride

Sodium fluoride		
Vφ0	**Sv**	**Molal volume**
1.45	1.34	1.86
1,76	1.32	1.45
1,23	1.87	1.34
1,87	1.43	1,41
1.45	1.34	1.64
1,98	1,53	1.23

CALCULATED MOLECULAR WEIGHT OF POLYMER

The total of the atomic weights of the individual atoms that make up a molecule is the molecular weight of a polymer. Fig 3 shows the average length of the polymer chains in the bulk resin. Not every polymer molecule in a given grade has the same molecular weight. Molecular weights have a distribution or range.

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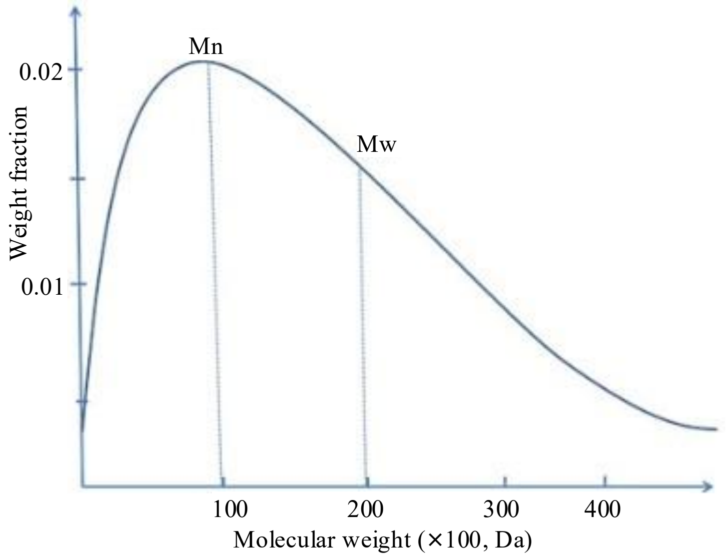

Figure 3. ~~Molecular weight of polymer~~

Figure 3 shows the two distinct molecular weight metrics are indicated on the molecular weight distribution chart. The molar-mass dispersity index is defined as the ratio Mw/Mn.

CONCLUSIONS

Optoelectronics has greatly benefited from the investigation and development of organic polymers. Measurements of apparent molar volumes and apparent molar compressibility indicate significant solute-solvent interactions in the DMSO solution. Furthermore, sodium fluoride forms structures in aqueous DMSO solutions but disrupts them in water, according to acoustic and volumetric studies. The volumetric and acoustic investigations are supplemented by the viscosity B-coefficient and associated factors. The proposed polymer materials have shown remarkable skills in light absorption, emission, charge, and energy transmission. They are distinguished by their flexibility, tunability, and possibility for economical manufacture. Optoelectronics is used in the medical field for cancer diagnosis, minimally invasive surgery (endoscopy), non-invasive, real-time vital sign monitoring (heart rate, pulse oximetry), and retinal implant vision restoration.

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