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Recent advancement in synthesis and properties of Polyaniline

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ABSTRACT: This review article, focused on recent advancement in synthesis and properties of polyaniline conducting polymers. Research and development in synthesis of polyaniline has been reviewed by different methods such as conventional method, ultrasound, Fenton process and substitution on polyaniline backbone as grafted polyaniline. By this Process of development with high accuracy of results shows a direct relationship with structure and properties. Polyaniline based on various structure modifications can give more interesting results for future applications.

KEYWORDS: Polyaniline, Fenton process, grafted polyaniline, conductivity, antimicrobial properties

I. INTRODUCTION

The monomer aniline was gotten first time in 1826, from the pyrolytic refining of indigo and was designated "Krystallin" in light of the fact that it created all around shaped crystalline salts with sulfuric and phosphoric corrosive. In 1840, Fritzsche likewise got lackluster oil from indigo, called it aniline from the Spanish word añil (indigo), and oxidized it to polyaniline (PANI). From the mid twentieth century on, periodic reports about the structure of polyaniline showed up in the writing. Lately, the investigation of polyaniline detonated and right now a huge writing on the combination, properties, and uses of polyaniline exists.

Polyaniline (PANI) is a conducting polymer (CP) of the semi-adaptable bar polymer family. Since the mid 1980s, PANI has caught the serious consideration of mainstream researchers. Among the group of CPs and natural semiconductors, polyaniline is extraordinary because of its simplicity of combination, ecological security and basic doping/dedoping science. In spite of the fact that the engineered techniques to deliver PANI are very straightforward, its component of polymerization and the correct idea of its oxidation science are very intricate. In view of its rich science, polyaniline is a standout amongst the most contemplated conducting polymers of the previous 50 years. Polymerized from the aniline monomer, polyaniline can be found in one of three romanticized oxidation states (Scheme 1).

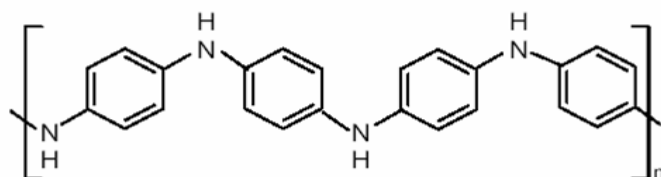
- **Leucoemeraldine** – white/clear and colorless
- **Emeraldine** – green for the emeraldine salt, blue for the emeraldine base
- **Pernigraniline** – blue/violet

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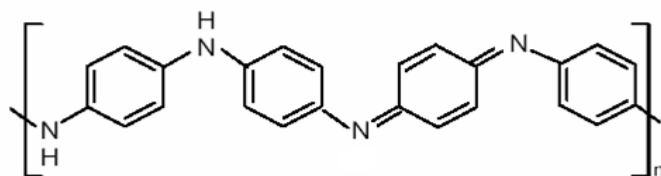
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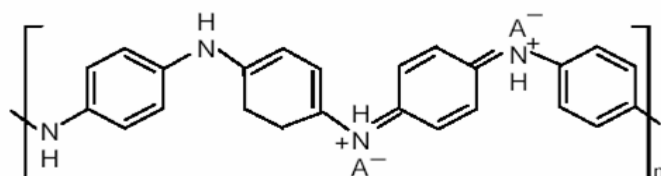
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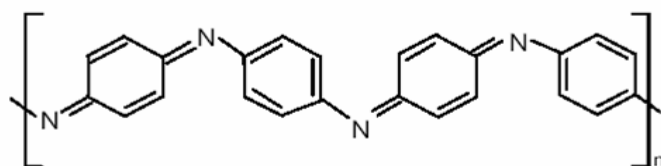
Leucoemeraldine



Emeraldine base



Emeraldine salt



Pernigraniline

Scheme 1: Different oxidation states of polyaniline

Leucoemeraldine is the completely reduced form of polyaniline. Pernigraniline is the completely oxidized state with imine connects rather than amine joins. The emeraldine type of polyaniline, frequently alluded to as emeraldine base (EB) is unbiased, whenever doped it is called emeraldine salt (ES), with the imine nitrogens protonated by acid. Emeraldine base is viewed as the most helpful type of polyaniline because of its high stability at room temperature and the way that, after doping with acid, the subsequent emeraldine salt type of polyaniline is electrically conducting [1]. Leucoemeraldine and pernigraniline are poor conductors, notwithstanding when doped with acid.

The shading change related with polyaniline in various oxidation states can be utilized in sensors and electrochromic devices [2]. In spite of the fact that colour is valuable, the best strategy for making a polyaniline sensor is apparently to exploit the emotional conductivity changes between the distinctive oxidation states or doping levels [3].

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The most widely recognized combination of polyaniline is by oxidative polymerization of aniline. Aniline has been dissolved in HCl or different acids (dopant) and ammonium persulphate (oxidant) has been included by drop wise addition and response has been proceeded for couple of hours.

Utilizing exceptional polymerization methods and dopants, the polyaniline powder can be recouped after polymerization and can be made dispersible and consequently valuable for various applications. A three phase show for the arrangement of emeraldine base has been proposed. In the primary phase of the response the pernigraniline salt (PS) oxidation state is formed. In the second stage pernigraniline is reduced to the emeraldine salt as aniline monomer gets oxidized to the radical cation. In the third stage this radical cation couples with ES salt [4].

In the doped emeraldine salt form, polyaniline is electrically conductive, which makes it appropriate for e.g. make of electrically leading yarns, antistatic coatings, electromagnetic protecting and adaptable anodes [5]. Another essential property is its situation in the electrochemical arrangement. Polyaniline is more respectable than copper and somewhat less honorable than silver which is the reason for its wide use in printed circuit board fabricating (as a last complete) and in erosion assurance [6]. Polyaniline is regularly created as long chain polymer totals, surfactant (or dopant) settled nanoparticle scatterings, or sans stabilizer nanofiber scatterings relying upon the engineered course. Surfactant or dopant balanced out polyaniline scatterings has been accessible for business deal since the late 1990s [7]. The persistently developing enthusiasm for the investigation of PANI throughout the years is for the most part a result of its different, however extraordinary properties of PANI, permitting its potential applications in different fields. It is an ecologically steady and exceptionally tunable leading polymer, which can be delivered as mass powder, cast movies, or filaments. Because of its minimal effort and substantial scale creation, it has different applications. A significant part of the basic portrayal of polyaniline has occurred over the most recent 20 years or somewhere in the vicinity, and is genuinely settled, despite the fact that the huge number of papers distributed over the most recent five years would demonstrate that polyaniline is still under much investigation.

Polyaniline is an average phenylene based polymer having an artificially adaptable – NH aggregate in a polymer chain flanked on either side by a phenylene ring. It can likewise be characterized as the straightforward 1, 4-coupling result of monomeric aniline particle. The protonation and deprotonation and different other physico-concoction properties of polyaniline is because of the nearness of the – NH-gathering. Polyaniline is the oxidative polymeric result of aniline under acidic conditions. There are a few reports of polyaniline found in the writing throughout the decades about the structure and protected part of aniline polymerization.

II. SYNTHESIS OF POLYANILINE BY DIFFERENT METHODS

Conventional method

The most widely recognized combination of polyaniline includes oxidative polymerization, in which the polymerization and doping happens simultaneously, and might be refined either electrochemically or synthetically. Electrochemical strategies have a tendency to have bring down yields than that gotten by substance methods [8]. Combination of polyaniline by concoction oxidative course includes the utilization of either hydrochloric or sulfuric acid within the sight of ammonium persulphate as the oxidizing operator in the watery medium. The key capacity of the oxidant is to pull back a proton from an aniline atom, without shaping a coordinate bond either with the substrate/intermediate or with the final product. Letheby has revealed that the proliferation of the polymer chain continues by a redox procedure between the developing chain (as an oxidant) and aniline (as a reducer) with expansion of monomer to the chain end. The high convergence of a solid oxidant, $(\text{NH}_4)_2\text{S}_2\text{O}_8$, at the underlying phase of the polymerization empowers the quick oxidation of oligo and polyaniline, and also their reality in the oxidized shape [9]. Ayad and Whdan [10] considered the concoction oxidation of aniline with ferric chloride, $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ in the HCl watery answers for frame polyaniline powder. Qi *et al.* [11] learned about the combination of PANI/ $\gamma\text{-Al}_2\text{O}_3$ composite by utilizing aniline, HCl, ammonium persulphate and $\gamma\text{-Al}_2\text{O}_3$. Cortes and Sierra got most extreme yield of polyaniline via doing polymerization of aniline at ideal states of the temperature, centralization of dodecylbenzensulfonic acid (dopant), grouping of ammonium persulphate (oxidant) and blending rate. These qualities were 25°C, 27 mmol, 11.5 mmol and 500 rpm, individually [12]. Sarifah *et al.* [13] announced amalgamation of camphor sulfonic acid (CSA)-doped polyaniline through oxidative polymerization of aniline with ammonium persulfate oxidant at 5°C. CSA has

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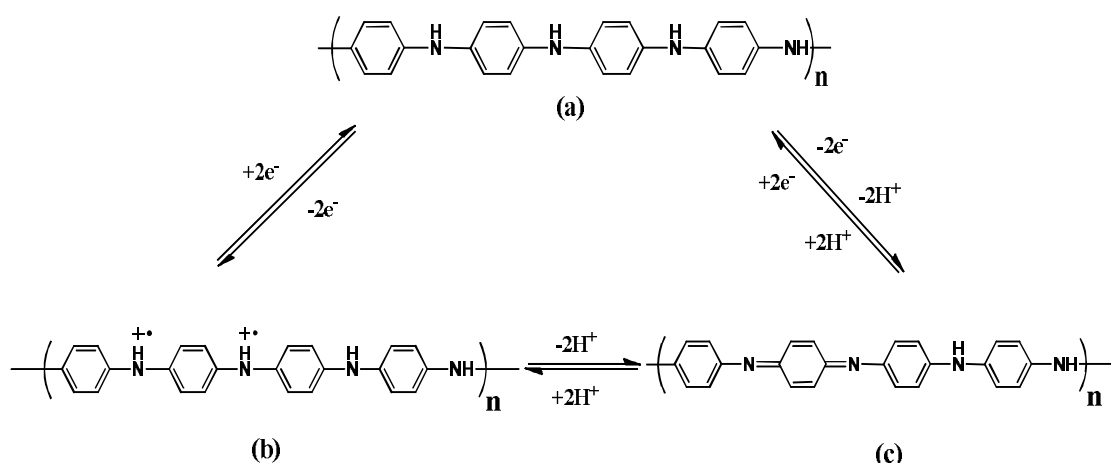
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been utilized as doping specialist with the end goal to enhance the solvency of the polymer. Kiran *et al.* [14] examined fluid twofold dopant ($\text{ZrOCl}_2/\text{AgI}$) in various proportions, for example, 1:1, 1:2 and 2:1 (w/w) for concoction doping to upgrade the conductivity of incorporated polyaniline. The doping of polyaniline is completed utilizing tetrahydrofuran as a dissolvable. Vivekanandan *et al.* [15] announced the electrochemical and synthetic oxidative union of polyaniline utilizing $\text{K}_2\text{Cr}_2\text{O}_7$ as an oxidant and H_2SO_4 as dopant. The conductivity of electrochemically combined polyaniline doped with H_2SO_4 at different voltages have been contrasted and polyaniline incorporated by substance strategy. Chiolerio *et al.* [16] announced the combination of PANI by oxidation polymerization beginning from the aniline dimer, along these lines keeping away from the utilization of a poisonous/mutagen substance, for example, aniline. With the end goal to work in watery stage, the invert expansion of the dimer in the oxidative arrangement is made. The chlorinated emeraldine salt of PANI is delivered and emeraldine base is set up by dedoping. Two distinctive doped PANI arrangements are delivered by solubilization of the emeraldine salt in dimethylsulphoxide and expansion of individually trifluorosulfonic acid and camporsulfonic acid, and afterward utilized as inks for the creation of inkjet-printed tracks of various geometries.

Wasu and Raut [17] detailed combination of polyaniline, polynitroaniline, poly m-toluidine and poly o-toluidine polymers by synthetic oxidation strategy utilizing ammonium persulfate as compound oxidant. Jangid *et al.* [18] examined ultrasonic helped polymerization to plan propelled leading polymeric materials. The technique is particularly helpful for planning PANI - EB in light of the fact that the readiness of conductive PANI should be in solid acidic medium and PANI is an effectively collected substance. With the end goal to combine semi-directing PANI-EB to accomplish with great conductivity and warm solidness, numerous scientists have received the system to co-dope PANI with both inorganic acids and natural acids. Be that as it may, the impact of inorganic acids and natural acids on warm strength of doped PANI has not been broadly explored. In this examination, inorganic (orthophosphoric corrosive) and natural acids (hippuric and tosic acids) doped polyanilines were integrated by oxidative polymerization of aniline. It has been seen that the incorporated emeraldine base type of polyanilines demonstrate sensibly great room temperature conductivity and better warm dependability. A biocatalytic methodology of leading polyaniline has been considered. This procedure changed over the PANI-ES to PANI-EB form (**Scheme 2**).



Scheme 2: Different oxidation states of PANI and their conversion in each other (a) Leucoemeraldine Base (LEB) (b) Emeraldine salt (ES) (c) Emeraldine base (EB).

Ultrasonic irradiation

Polyanilines can likewise be incorporated by ultrasonic light. It has been seen that ultrasound can prompt new compound responses and enhance the response rate, and hence opens up another science i.e., sonochemistry. Ultrasound improves the polymerization rate of aniline that is normally moderate under ordinary blending in reverse microemulsion and adds to create round nanoparticles. Likewise, ultrasound light advances the dissemination of dopant

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atoms and enhances the level of doping. Polymerization of aniline happened in the bound nanoreactor in microemulsion and fortifies the hydrogen-holding of amine and imine of PANI atomic chains, which enhances the level of crystallinity. Wang *et al.* [19] revealed the blend of polyaniline nanofibers by the dropwise expansion of an APS (ammonium persulphate) answer for an aniline arrangement within the sight of ultrasonic illumination. PANI nanofibers with higher polymer yields were effectively arranged in this examination due to the powerful anticipation of the essential PANI nanofibers from auxiliary development and agglomeration. Xia and Wang [20] detailed the ultrasonic helped reverse microemulsion polymerization strategy to get ready propelled leading polymeric nanomaterials. The strategy is particularly helpful for planning of zero measurement PANI nanoparticles on the grounds that the readiness of conductive PANI should be in solid acidic medium and PANI is an effortlessly collected substance. Valle *et al.* [21] examined the impact of ultrasound on nucleation and growth mechanisms (NGM) from the separate homeless people got amid the electro-polymerization of ortho-anisidine (OAN) and aniline (ANI), utilizing a potential advance methodology. Ai and Jiang [22] revealed the union of polyaniline nanosticks with a normal measurement of around 40 nm and a length of around 150 nm or longer by an easy format free technique in watery arrangement under ultrasonic light.

Ubramanian *et al.* [23] has been accounted for a strategy for readiness of Ni^{2+} doped PANI by synthetic oxidative polymerization with the assistance of ultrasonic light. The morphological component of above combined PANI has been watched distinctive when it is integrated by regular strategy. Thus remarkable change in electrochemical property was seen because of its interconnected nano-fibrillar morphology. In this manner, these highlights make it a promising substance for as an anode material in supercapacitor applications.

Microwave irradiation

The very first rapid and facile microwave assisted (MWA) synthesis of polyaniline nanofibers have been synthesized by Gizdavic-Nikolaidis *et al.* [24]. During study of this method it has been observed that, it is very fast, clean and convenient method for the synthesis of PANI nanofibers at ambient temperature. By this method high yield of PANI nanofibers has been obtained in short reaction time and also in very less energy consumption. Therefore, it has been suggested that this method can be used as an alternative for large scale production in industries as compared to conventional synthesis. As a result, it has been observed that polyaniline nanofibers have been synthesized first time under MWA and 76.2% yield and weight average molecular weight was 17473 g/mol obtained in 5 min reaction time. When this same reaction proceed for 20 min then obtained yield was 78.8% and weight average molecular weight 18689 g/mol. Synthesized PANI nanofibers has been characterized by different much in which SEM give information about morphology and structure elucidation has been done by FTIR and Raman spectroscopy. High penetration power and specific heating mechanisms of microwave radiation are responsible for fast reaction kinetics. Therefore, microwave assisted synthesis method of PANI nanofibers is very convenient and eco friendly.

2.4 Fenton process

Combination of polyanilines may likewise be completed by cutting edge oxidative polymerization process utilizing Fenton reagent ($\text{H}_2\text{O}_2\text{-Fe}^{2+}$) as an oxidant shown in **Figure 1**.

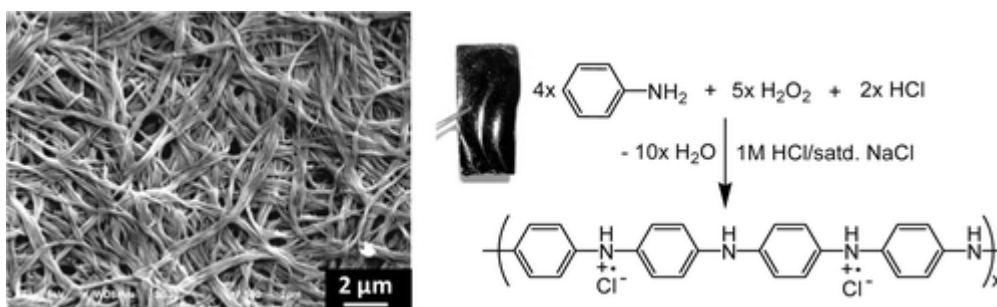


Fig. 1 – Synthesis of PANI by fenton process (Kind permission of Reference 24)

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Pure H_2O_2 is considered excessively feeble oxidatively, making it impossible to polymerise aniline to polyaniline. At room temperature there is no perceptible response, and at higher temperatures the response yields a dark brown insulating solid. By basically doing the response at high ionic quality, H_2O_2 can be utilized as a successful oxidant to accomplish the coveted straight make a head-to-tail coupling of aniline units bringing about polyaniline that isn't just exceedingly leading yet additionally made totally out of a nonwoven work of nanofibers [25]. In spite of the fact H_2O_2 is an essential oxidant which is generally utilized in industry. Its redox potential is 1.77V concerning standard calomel electrode (SCE), sufficiently high for aniline polymerization, however not all that high that response take puts enthusiastically. Its reduction product is only H_2O , in this manner significantly rearranging the post treatment. Another favorable position is plausibility of reusing the response medium since it doesn't contain any hurtful segments amid aniline polymerization. Along these lines, H_2O_2 approach is anything but difficult to industrialize. In any case, when H_2O_2 alone is utilized as oxidant, the response rate is to a great degree low. With the end goal to get brilliant PANI, the response movement of H_2O_2 must be improved [26]. Zhu and Mu [27] detailed the synthetic polymerization of aniline in the $\text{H}_2\text{O}_2\text{-Fe}^{2+}$ framework. The response conditions were streamlined for the response yield, electrical conductivity and consistency of PANI. Ayad and Zaki [28] detailed PANI movies and powder tests was made utilizing Fenton reagent as oxidizing specialist in watery sulfuric acidic medium. Huang *et al.* [29] announced the one-pot blend of polyaniline doped with progress metal particles utilizing H_2O_2 as oxidant. It has been seen that PANI doped with metal particles has distinctive geometrical shapes from that of PANI doped with HCl. Incorporation of metal particles in PANI spine brings about expanding electrical conductivity by diminishing band hole and in this manner increment the particular capacitance of Zn-PANI and Cu-PANI contrasted with that of H-PANI. Blaha *et al.* [30] revealed the reactant polymerization of aniline with $\text{FeCl}_3/\text{H}_2\text{O}_2$ framework, which can significantly bring down tainting of slick polyanilines by side-items normal for stoichiometric polymerization. Be that as it may, chemically arranged PANIs display diminished conductivity most likely because of side responses including radicals created as indispensable parts of the $\text{FeCl}_3/\text{H}_2\text{O}_2$ framework. Synergist polymerization of ANI with $\text{FeCl}_3/\text{H}_2\text{O}_2$ framework was observed to be the response of around second request concerning ANI and gives PANIs of a decent quality just when $[\text{H}_2\text{O}_2]$ in the response blend was kept low, i.e., under-stoichiometric proportions of $[\text{H}_2\text{O}_2]/[\text{ANI}]$. At over-stoichiometric proportion of $[\text{H}_2\text{O}_2]/[\text{ANI}]$, PANIs of lower conductivity, more terrible spectroscopic qualities and expanded size of PANI nanostructures were acquired; all things considered, these PANIs were not over oxidized to pernigraniline state. Shankramma *et al.* [31] learned about Polyaniline- TiO_2 (PANI- TiO_2) nanocomposite (**Figure 2**). These indicated relatively comparative photocatalytic movement under UV and noticeable light and additionally in the sunlight based light. These outcomes demonstrate that PANI- TiO_2 nanocomposites are great photocatalysts for the treatment of modern wastewater containing Rhodamine B-19 color.

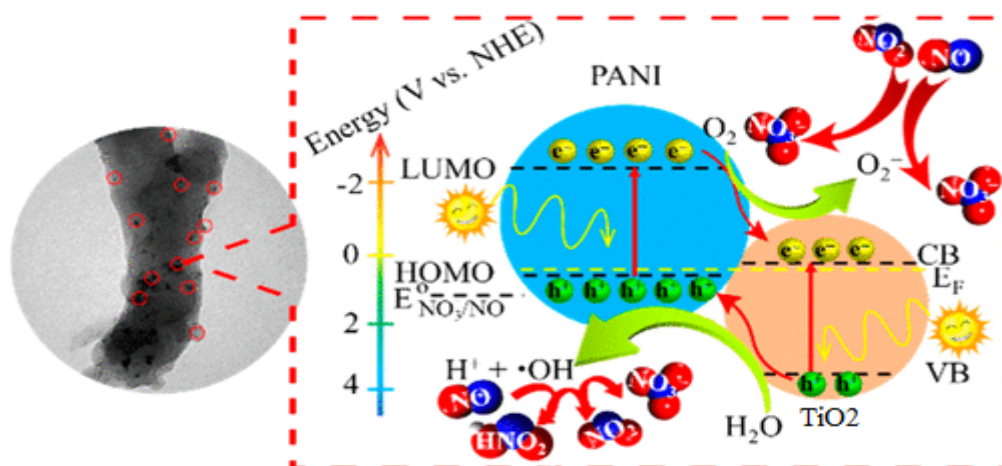


Fig. 2 – Photocatalytic mechanism of TiO_2/PANI nanocomposite (Kind permission of Reference 31)

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Grafted polyanilines

In the previous couple of years, fragrant directing polymers, for example, polypyrrole, polythiophene or polyaniline have gotten impressive consideration inferable from their great electrical, optical and electrochemical properties. Be that as it may, because of the firmness of its spine, polyaniline is relatively insoluble in like manner natural solvents. Subsequently, its post union processability is very troublesome. As a rule, the solubilization of a polymer can be accomplished through functionalization of beginning material with a reasonable side bind before polymerization. In spite of the fact that polyaniline indicates great conductivity (1.2 S cm^{-1}), yet it is insoluble in like manner natural solvents. Then again, poly(halogensubstituted aniline)s are dissolvable in some natural solvents like N-methylpyrrolidinone, dimethylformamide, tetrahydrofuran, dimethylsulfoxide and acidic corrosive upto 80% v/v, however their conductivity stay low ($\sigma < 10\text{--}11 \text{ S cm}^{-1}$) [32]. Thinking about these information, the amalgamation of a copolymer that consolidates the conductivity of polyaniline and the dissolvability of polyhalogenanilines would be of intrigue. In this way, the copolymerization of aniline with halogenanilines should lead, upon appropriate change of the copolymer organization, to a solvent and directing or semiconducting material. As of not long ago, this system was utilized just by a couple of specialists for the union of another sweet-smelling leading polymer. The synthetic copolymerization of aniline and 2, 5-dibromoaniline or 2,6-dibromoaniline by oxidation with $\text{K}_2\text{Cr}_2\text{O}_7$ in H_2SO_4 /acetonitrile medium has been done [33]. At the point when substituted aniline division is expanded in the copolymer, the electrical conductivity (σ) diminishes; this impact is more imperative when 2,6-dibromoaniline is utilized. In this manner, the conductivity can be controlled in a wide range, from 1.2 to $10^{-6}\text{--}10^{-11} \text{ Scm}^{-1}$ relying upon the substituted aniline and the feed proportion. The connection between copolymer pieces and monomer feed molar proportions demonstrates that the aniline is somewhat more receptive than dibromoanilines amid the copolymerization procedure. Every one of the copolymers were appeared to be more processable than polyaniline [34]. The PANI/ Co_3O_4 composites have been orchestrated by in situ polymerization within the sight of Co_3O_4 nanoparticles and HCl as the dopant [35].

Yue and Epstein [36] have orchestrated self doped polyaniline through the response between an emeraldine base type of polyaniline and seething sulfuric corrosive. The subsequent polymer was a dissolvable sort with ring-substituted sulfonic corrosive gathering and having a conductivity of around 0.1 Scm^{-1} . Expanded solvency has been accounted for alkyl-and alkoxy-substituted polyanilines [37].

A mucopolysaccharide, chitosan has been joined with polyaniline through oxidative-radical copolymerization utilizing ammonium persulfate in acidic medium [38]. The joining conditions were widely contemplated by shifting uniting parameters. Every one of the discoveries have been researched and a conceivable component for the unite copolymerization has been proposed. Ch-g-PANI displayed electrical conductivity, which increments with the degree of uniting. Its electrical conductivity is additionally impacted by pH and indicated pH exchanging electrical conduction conduct when presented to NH_3/HCl vapors. The use of directing biomaterial, for example, Ch-g-PANI in the electronic gadgets particularly for the manufacture of sensor gadgets would be appealing not just as far as item cost and natural security yet additionally from a materials science perspective [39].

Polyaniline covered leading textures have been acquired by concoction oxidation of aniline by potassium peroxydisulfate on polyester textures. Two unique acids have been utilized to do the union (HCl and H_2SO_4), getting the best aftereffects of conductivity with the last one. The leading textures have additionally indicated electrochromic properties, changing its shading from green yellowish to dull green. The solidness of the covering has been assessed by methods for washing and rubbing speed tests [40].

Directing polyaniline/ γ - Fe_2O_3 (PANI/FE) composites have been integrated utilizing an in situ affidavit method by setting fine-evaluated γ - Fe_2O_3 in a polymerization blend of aniline. It has been seen that the conductivity increments up to an organization of 20 wt % of γ - Fe_2O_3 in polyaniline and declines from that point. The underlying increment in conductivity is ascribed to the broadened chain length of polyaniline, where polarons have adequate vitality to jump between ideal locales. Past 20 wt % of γ - Fe_2O_3 in polyaniline, the obstructing of charge bearer bounce happens, decreasing conductivity esteems. The attractive properties, for example, hysteresis qualities and standardized a.c. helplessness have additionally been estimated, which demonstrate a solid reliance on substance of γ - Fe_2O_3 in polyaniline. Due to superparamagnetic conduct of these composites, they may discover broad mechanical applications, particularly to retain and protecting applications in microwave frequencies [41].

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Polyaniline (PANI), N-methyl-and N-ethyl-PANI, 2-and 3-ethyl-PANI and 2,6-dimethyl-and 3,5-dimethyl-PANI have been incorporated utilizing ammonium persulfate as impetus. The concoction structures of the N-methyl-and N-ethyl-PANI have been found to contain quinoneimine units along the polymer chain. In the doped express the N-alkyl-PANIs demonstrate the polaronic band change in the close infra red area of the range, at longer wavelength than doped unsubstituted PANI [42].

Jayanna *et al.* [43] have detailed union of polyaniline/ ZnFe_2O_4 nanocomposites by utilizing a basic and cheap one-advance in-situ polymerization technique within the sight of ZnFe_2O_4 nanoparticles. The a.c. conductivity of polyaniline/ ZnFe_2O_4 nanocomposites has been observed to be 0.695 Scm^{-1} at room temperature.

Zhao *et al.* [44] learned about a useful structure made up of $\text{Mn}_{0.5}\text{Zn}_{0.5}\text{Fe}_2\text{O}_4$ -polyaniline nanocomposites with high dielectric retaining properties and electromagnetic protecting viability at low frequencies. It has been effectively manufactured through an easy in situ emulsion polymerization. Polyaniline (PANI) has been doped with hydrochloric corrosive to enhance its electrical properties and associations with ferrite nanoparticles. The electrostatic and paramagnetic power and hydrogen holding unequivocally reinforced or gathered ferrite nanoparticles on the polyaniline surface and enhanced its warm security. The ferrite-joined polyaniline nanostructures have been shown as a promising practical material for retaining the electromagnetic microwaves due to a lot of dipole polarizations in the polymer spine and at the interfaces of the ferrite nanoparticles and polyaniline nanofibers.

The usage of directing polyaniline emeraldine salt (PANI-ES) and inherent leucoemeraldine polyaniline (PANI-LEB) for the blend of diglycidyl ether bisphenol A - united PANI (DGEBA- g- PANI) through anionic copolymerization has been portrayed by Rasid *et al.* [45]. Results got showed that the join copolymer displayed higher electrical and warm conductivities than that of the mix partner.

Polyaniline N-united with poly(ethyl acrylate) (PEA) has been incorporated by the joining of bromo-ended poly (ethyl acrylate) (PEA-Br) onto the leucoemeraldine type of PANI. PEA-Br has been orchestrated by the particle exchange radical polymerization of ethyl acrylate within the sight of methyl-2-bromopropionate and copper(I) chloride/bipyridine as the initiator and impetus frameworks, individually. The leucoemeraldine type of PANI was deprotonated by butyl lithium and after that responded with PEA-Br to get ready PEA-g-PANI join copolymers containing diverse measures of PEA by means of a N-uniting response [46].

Kanzhu *et al.* [47] has been learned about the union and portrayal of poly(ethylene glycol)- united extended graphite/polyaniline (PEG-joined EG/PANI) as a novel ecofriendly composite material. EG as substrate arranged from expandable graphite has been right off the bat incorporated by in-situ polymerization at the nearness of aniline (A) to acquire EG/PANI, and afterward unite polymerization with as-arranged PEG-joined PANI (PEG-g-PANI) composite under no extreme conditions.

Vani *et al.* [48] researched the advancement of new (sodium alginate-gelatin (Droop))- g-poly(acrylic acid)/polyaniline (SAPAPN) from sodium alginate/gelatin mix by cross connecting with glutaraldehyde, trailed by joining with poly(acrylic corrosive) and polyaniline by free extreme polymerization utilizing ammonium persulfate. Liu *et al.* [49] detailed a novel course of union of various leveled polyaniline united reduced graphene oxide (rGO) cross breed materials of polyaniline nanorods covalently fortified on the surface of rGO. Uniting of amino phenyl bunches on rGO happens by means of diazonium treatment. At that point the PANI nanorods were adjusted vertically on rGO to develop a three dimensional (3D) structure. The 3D structure could abbreviate the electronic transmission way and shape bottomless space for electrolyte particles. This one of a kind 3D auxiliary material can be utilized as a promising sort of terminal in the up and coming age of high vitality thickness and high power thickness electrochemical supercapacitors. El-Dib *et al.* [50] detailed the blend of chitosan immobilized bentonite (CIB) (5% chitosan content) in 2% acidic corrosive arrangement, trailed by cross connecting, utilizing epichlorohydrin (ECH). The got cross connected chitosan immobilized on bentonite (CIB-ECH) and CIB composites were united with polyaniline through oxidative radical copolymerization utilizing ammonium peroxydisulfate in acidic medium to deliver PANI-joined cross connected chitosan immobilized on bentonite (PANI-g-CIBECH) and PANI-united chitosan immobilized on bentonite (PANI-g-CIB) composites, individually. Massoumi *et al.* [51] completed union of N-substituted polyaniline by chlorine ended chloroacetyl chloride consolidation and methyl methacrylate polymerization done on to the leucoemeraldine frame. Polyaniline-united polymethylmethacrylate was set up as copolymer of methylmethacrylate through atom transfer radical polymerization (ATRP) utilizing polyaniline macroinitiator. Right off the bat, polyaniline was set up by

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compound oxidation. The macroinitiator was incorporated by means of response of leucoemeraldine's nitrogen with chloroacetyl chloride. Studies were made to enhance physico-concoction properties of PANI by shifting the joining proportion of chitosan. Polyaniline as a conductive polymer and chitosan as a characteristic polymer have been responded with formaldehyde as joining specialist and potassium persulfate as an initiator. The impact of utilizing particular groundwork, distinctive proportion of monomers and the dissolvability of orchestrated copolymer has been examined and dissected by Sedaghat [52]. Zhencui *et al.* [53] announced the blend of novel synthetically adjusted cathode dependent on polyaniline/titanium carbide nanoparticles (PANI/nano-TiC) by electrochemical copolymerization of aniline and nano-TiC. It has been seen that, in 0.5 M H₂SO₄, the PANI/nano-TiC anode indicates three reversible redox crests with the formal capability of +0.23, +0.45, +0.78V, individually. The electrochemistry of the PANI/nano-TiC anode depends unequivocally on the pH estimation of the arrangements. With the expansion of the pH esteem, the electrochemical property of PANI/nano-TiC cathode winds up feeble. Moreover, the PANI/nano-TiC terminal shows electrocatalytic capacity for the decrease of nitrite. Rathinam and Sankaran [54] announced the polyaniline grafted chitosan (PGC) as an adsorbent for the evacuation of Pb (II) and Cd (II) particles from watery arrangement. It has been seen that the adsorption of Pb (II) and Cd (II) particles onto the PGC was not influenced by nearness of other normal metal particles. The balance information were fitted to Langmuir, Freundlich and Dubinin-Radushkevich isotherm models. The greatest monolayer limit acquired from the Langmuir isotherm was 16.07 and 14.33 mg/g for Pb (II) and Cd (II) particles, individually. The motor information were fitted well to the pseudo-second-arrange dynamic model. The relevance of the PGC has been tried for the evacuation of Pb (II) and Compact disc (II) particles from a genuine water test spiked with Pb (II) and Cd (II).

III. PROPERTIES OF POLYANILINE

Conductivity

Directing polymers will be polymers containing a broadened pi conjugated framework, made up of cover of independently possessed p - orbitals in the foundation of the polymer chain [55]. In spite of the fact that directing polymers have a generally extensive number of delocalized pi electrons, a genuinely expansive vitality hole exists between the valence band and the conduction band (more noteworthy than 1 eV), in this manner these polymers are viewed as semi-leading. These polymers must be doped (generally significance modifying the quantity of pi electrons) with the end goal to render the polymers genuinely directing.

In conjugated polymers the electronic arrangement is in a general sense extraordinary, where the substance holding prompts one unpaired electron for every carbon particle. The orbitals (having one electron in each) on progressive carbon particles along the spine cover, prompting electron delocalization along the foundation of the polymer [56]. This electron delocalization gives the roadway to charge portability along the foundation of the polymer chain. Thusly, the electronic structure in directing polymers is dictated by the chain symmetry, i.e. the number and sort of particles inside the recurrent unit, with the outcome that such polymers can display semiconducting or even metallic properties.

Electrically leading polymers are assigned as the fourth era of polymeric materials. Electrically directing polymers are broadly conjugated in nature and in this way, it is trusted that they have a spatially delocalized band-like electronic structure. These groups come from the part of collaborating atomic orbitals of the constituent monomer units in a way reminiscent of the band structure of strong state semiconductors. It is by and large concurred that the component of conductivity in these polymers depends on the movement of charged imperfections inside the conjugated structure. The charge transporters, either positive p-sort or negative n-type, are the results of oxidizing or decreasing the polymer individually. The most straightforward conceivable type of directing polymer is obviously the arche compose polyacetylene (CH)_x. Polyacetylene itself is excessively insecure, making it impossible to be of any down to earth esteem, its structure comprises the center of every conjugated polymer. Researchers had recommended that appropriately substituted polyacetylene particle would display superconductivity at room temperature. The electrical conductivity of the request of 10⁻⁵ S/cm for trans polyacetylene test has been accounted for [57]. Polyacetylene could achieve large amounts of electronic conductivity when oxidized by appropriate reagents started a noteworthy research [58]. Since late seventies, a substantial number of polymers have been added to the rundown of leading polymers, for example, polypyrrole [59], polythiophene [60], polyparaphenylene [61], polyphenylene sulfide [62], polyaniline [63],

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polyphenylene vinylene and so forth [64]. Doping the polymers makes new states (contributor or acceptor states), which exist inside the band hole [65] and are vigorously available to the pi electrons, bringing about huge increment in conductivity [66]. Truth be told, the conductivity of doped polymers might be up to ten requests of greatness more prominent than that of the unbiased (undoped) polymers [67]. The idea of conductivity of conjugated polymers was immediately widened from polyacetylene [68] to incorporate a conjugated hydrocarbon and fragrant heterocyclic polymers, for example, poly (p-phenylene) and polythiophene [69]. The conductivity of different doped and undoped polymers, some regular semiconductors and metals are introduced in Table 1.

Table 1 - Conductivity of various doped and undoped polymers, some common semiconductors and metals

MATERIAL	CONDUCTIVITY (S/cm)
Gold, Silver, Copper	$\sim 10^6$
Doped trans- polyacetylene	$\sim 10^5$
Doped polyaniline	$\sim 10^1$
Germanium	$\sim 10^{-2}$
Silicon	$\sim 10^{-6}$
Undoped trans- polyacetylene	$\sim 10^{-6}$
Undoped polyaniline	$\sim 10^{-10}$
Glass	$\sim 10^{-10}$
Quartz	$\sim 10^{-12}$
H ₂ SO ₄ doped polyaniline	$\sim 10^{-8}$
Dodecylbenzene sulfonic acid-doped Polyaniline	$\sim 10^{-8}$

As the directing polymers might be doped to different degrees, there is a component of control in doping level, consequently the conductivity. This capacity to tailor the polymer's electrical properties embodies the flexibility of directing polymers.

Polyacetylene, polythiophene, polypyrrole, poly (p-phenylene vinylene) are normally utilized leading polymers. These polymers are expensive, less steady mechanically in the wake of doping and troublesome in preparing. Subsequently, here polyaniline (PANI) is chosen for study in light of the fact that polyaniline inferable from its simplicity of blend, noteworthy ecological steadiness and high conductivity in the doped frame, has stayed a standout amongst the most completely examined directing polymers.

The conductivity of PANI relies upon the level of doping, oxidation state, molecule morphology, crystallinity, between or intrachain associations, atomic weight, and so forth [70-75]. The conductivity of polyaniline first increments with increment in temperature and after that abatements. It very well may be clarified by the molecule measure which has huge impact on the conductivity of polyaniline. A diminishing in molecule size can prompt more successful doping, higher level of crystallinity and higher conductivity. Notwithstanding, too little molecule size will deliver some grid deformity, more limited electron and lower conductivity.

Molecular forces in polymer

Generally strong covalent bonds are present between atoms in one chain and Vander Waals force, hydrogen bridges' etc are present between two chains of polymer. Vander Waals bonds are responsible for crystalline state of polymer. Entanglements are physical kind of attraction in amorphous state of polymers.

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Crystallinity in Polymers

Many thermoplastics will crystallize to some extent, when the molten polymer is cooled below the melting point of the crystalline phase. Polymers are never completely crystalline. This is because there are enormous number of chain entanglements in the melt that make it impossible for polymer chain, to be fully aligned to form a 100% crystalline polymer during crystallization. Several methods like wide-angle X-ray scattering (WAXS) method, density method, and differential scanning calorimetry (DSC) are used to measure degree of crystallinity. From density method –

$$\% \text{ Crystallinity} = \frac{\rho_c(\rho_s - \rho_a)}{\rho_s(\rho_c - \rho_a)} \times 100 \quad \dots\dots\dots(1.1)$$

Where ρ_s = density of sample, ρ_a = density of the completely amorphous polymer, ρ_c = density of the completely crystalline polymer.

Percentage crystallinity depends on several factors like rate of cooling, (faster cooling, less crystallinity); types of polymer (homopolymer has more crystallinity whereas copolymer has less crystallinity). The higher percentage of crystallinity gives a higher strength to polymer. When polymers are crystallized, they form spherical structures called spherulites.

WAXS is a powerful method of determining the degree of crystallinity. Since the scattering from the crystalline regions gives relatively sharp peaks as compared to a broad ‘hump’ due to scattering from non-crystalline areas, the degree of crystallinity can be determined from the relative areas under the crystalline peaks and the amorphous hump.

Mass fraction of crystalline regions X_c is given by -

$$X_c = \frac{A_c}{A_c + A_a} \quad \dots\dots\dots(1.2)$$

where A_a is the area under the amorphous hump and A_c is the remaining area under the crystalline peaks.

Thermal transitions in polymers

The term “transition” means a change of state induced by changing the temperature or pressure. Two major thermal transitions are the glass transition (T_g) and the melting (T_m).

Crystalline polymers – There is a discontinuous change in specific volume at T_m . It is transforming solid with an ordered structure to viscous liquid with a highly random structure.

Amorphous polymers – There is a continuous change in specific volume so T_m will observed but there is an increase in slope at glass transition temperature (T_g). Below glass transition temperature, polymers are usually brittle and glass like in mechanical behaviour and above glass transition temperature, polymers are usually more elastic.

Semicrystalline polymers - It is intermediate states between crystalline and amorphous polymer, which shows both transitions. A thermoplastic polymer may be completely amorphous in solid state, which means that the polymer molecular chains in the specimen are arranged in a totally random fashion.

Glass transition temperature depends on (a) chain flexibility (b) molecular structure (steric effects) (c) molecular weight and (d) branching and cross linking.

Polymers in Solution

For linear and branched polymers, liquids can usually be found that will dissolve the polymers completely to form a homogeneous solution, whereas cross linking networks will only swell, when brought in contact with compatible liquids. When an amorphous polymer is mixed with a suitable solvent, it disperses in the solvent and behaves as though it too is a liquid. In a “good” solvent, classed as one that is highly compatible with the polymer, the liquid-polymer interactions expand the polymer coil from its unperturbed dimensions in proportion to the extent of these interactions while in a “poor” solvent, the interactions are fewer, and coil expansion or perturbation is restricted.

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The fundamental thermodynamic equation used to describe these system relates the Gibbs free energy function G to the enthalpy H and entropy S ; i.e., $G = H - TS$.

A homogeneous solution is obtained when the Gibbs free energy of mixing $\Delta G^M < 0$, i.e., when the Gibbs free energy of the solution G_{12} is lower than the Gibbs functions of the components of the mixture G_1 and G_2 .

$$\Delta G^M = G_{12} - (G_1 + G_2) \dots\dots\dots(1.3)$$

Solution are classified into two parts

Ideal solution - ($\Delta H_{\text{mix}} = 0$, $\Delta V_{\text{mix}} = 0$). It is rare occurrence

Real (Non-ideal solution) ($\Delta H_{\text{mix}} \neq 0$, $\Delta V_{\text{mix}} \neq 0$)

- i. Athermal solutions, where $\Delta H^M = 0$, but ΔS^M is not ideal.
- ii. Regular solution, where ΔS^M is ideal, but $\Delta H^M \neq 0$
- iii. Irregular solution, in which both ΔS^M and ΔH^M deviate from their ideal values.

Polymer solution tend to fall into category (iii), and the non-ideal behaviour can be attributed not only to the existence of a finite heat of mixing but also to the large difference in size between the polymer and solvent molecules.

Solubility Parameters

A measure of the intermolecular attraction forces in a material is provided by the cohesive energy, which approximately equals the heat of vaporization (for liquids) or heat of sublimation (for solids) per mole. The cohesive energy of a volatile liquid can be estimated from the work required to vaporize a unit amount of material. The cohesive energy density (sum of the intermolecular energies per unit volume) is at its equilibrium value in the liquid state and it

is zero in the vapour state. By these reasoning, the cohesive energy density in the liquid state is $\frac{\Delta E_v}{V}$, in which, ΔE_v

is the molar energy of vaporization and V is the molar volume of the liquid.

The square root of this cohesive energy density is known as the solubility parameter (δ),

$$\delta = \left(\frac{\Delta E_v}{V} \right)^{1/2} \dots\dots\dots(1.4)$$

$$\delta = (\Delta H_v - RT)^{1/2} / V \dots\dots\dots(1.5)$$

$$= \left[\frac{(\Delta H_v - RT)\rho}{M} \right]^{1/2} \dots\dots\dots(1.6)$$

where ΔH_v is the molar enthalpy of vaporization and ρ is the density of liquid with molecular weight M .

Solubility parameters of a solvent can also be correlated with the structure, molecular weight and density of solvent molecule.

Solubility can be expected, if the absolute value of $(\delta_1 - \delta_2)$ is less than unity and there are no strong polar or hydrogen bonding interactions in either the polymer or the solvent.

The most comprehensive approach to resin solubilities has been that of Hansen, where the solubility parameter is divided into three components. The basis of three dimensional solubility parameter system is the assumption that the energy of evaporation i.e. the total cohesive energy ΔE_t , which holds a liquid together can be divided into contribution from dispersion (London) force ΔE_d , polar forces ΔE_p , and hydrogen-bonding forces ΔE_h . Thus-

$$\Delta E_t = \Delta E_d + \Delta E_p + \Delta E_h \dots\dots\dots(1.6)$$

Dividing this equation by the molar volume of a solvent, V results in-

$$\frac{\Delta E_t}{V} = \frac{\Delta E_d}{V} + \frac{\Delta E_p}{V} + \frac{\Delta E_h}{V} \dots\dots\dots(1.7)$$

$$\delta_t^2 = \delta_d^2 + \delta_p^2 + \delta_h^2 \dots\dots\dots(1.8)$$

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where δ_d = Solubility parameter due to dispersion forces, δ_p = Solubility parameter due to dipole forces and δ_h = Solubility parameter due to hydrogen bonding (or in general due to donor – acceptor interaction)

Polymer molar masses

Estimation of the molar mass of a polymer is of considerable importance as the chain length can be a controlling factor in determining solubility, elasticity, fiber – forming capacity, tear strength and impact strength in polymers. If the molecular weight is computed by dividing the total mass by the total number of molecules, which is equivalent to weighting the molecular weight of each species by its mole fraction, the number average molecular weight \bar{M}_n is obtained. Alternatively, the molecular weight of each species may be weighted by its weight fraction to give the weight average molecular weight \bar{M}_w . The relation between \bar{M}_n and \bar{M}_w depends on the form of molecular weight distribution for homogenous sample of a polymer $\bar{M}_n = \bar{M}_w$, where as for heterogeneous sample $\bar{M}_w > \bar{M}_n$. The ratio \bar{M}_w/\bar{M}_n is commonly taken to be a measure of the polydispersity of the sample for synthetic polymer. The value of polydispersity (PDI) is more than one. The number average molecular weight are determined by osmotic pressure, elevation of boiling point, depression of freezing point, non –aqueous conductometric titration and end group analysis. The weight average molecular weights are determined by light scattering method.

$$\bar{M}_n = \sum n_i M_i = \frac{\sum N_i M_i}{\sum N_i} \quad \dots\dots\dots(1.9)$$

$$\bar{M}_w = \sum w_i M_i = \frac{\sum N_i M_i^2}{\sum N_i M_i} \quad \dots\dots\dots(1.10)$$

Gel permeation chromatography (GPC) is a type of size exclusion chromatography (SEC), that separate analytes on the basis of size. The technique is often used for the analysis of polymers. GPC allows for the determination of M_n , and M_w as well as PDI. The molecular weight distribution of the polyaniline nanofibers has been determined using gel permeation chromatography. Although a bimodal distribution of molecular weight observed, similar to that of conventional polyaniline in which the area under the high molecular weight peak (61.7%) is considerably larger than that under the low molecular weight peak (38.3%).

Electrical Properties

The most widespread electrical application of polymers is the insulation of cables. In recent years, high performance polymers have become important in the electronic industry, as encapsulants for electronic components, interlayer dielectrics and printed wiring board materials. The dielectric constant (or permittivity) ϵ and the dissipation factor (or power factor or electrical loss tangent) $\tan \delta$, which are dimensionless quantities, are the key electrical properties of polymers.

The dielectric constant ϵ is a measure of the polarization of the medium between two charges, when this medium is subjected to an electrical field. A larger value of ϵ and $\tan \delta$ implies greater polarization of the medium between the two charges.

The vacuum contains nothing that could be polarized, and therefore, has $\epsilon = 1$. All materials have $\epsilon > 1$. The dielectric constant of a non- conducting material is generally defined as the ratio of the capacities of a parallel plate condenser with and without the material placed between plates. Dissipation factor ($\tan \delta$) of polymers is a function of temperature, frequency and relaxation time whereas dielectric constant is a function of temperature, frequency, structure, composition, crystallinity, impurities, fillers, plasticizers and moisture of polymer.

Dielectric Strength

Electrical debasement and separate marvels confine the utility of polymers in numerous applications running from electrical links protection to usage in cutting edge electronic gadgets. The key property of a polymer in connection to its electrical debasement and breakdown conduct is its dielectric quality. It has units of volts/length. It is influenced by an assortment of elements including the polymeric structure, the example geometry and the testing conditions. Dielectric quality is additionally the electronic structure of the polymer and specifically, chooses its band hole. The band hole is the vitality distinction between the highest point of the valence band and the base of the conduction (Band hole is the vitality contrast between the most noteworthy involved and the least vacant atomic orbitals of a strong). The

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band holes of polymers go from extensive qualities; or, in other words covers for polymers just containing σ electrons and to little qualities; or, in other words worked from discrete recurrent units with conjugated π electron spines lastly to zero for some one of a kind fragrant step polymers.

Thermal analysis of polymers

Thermal analysis is defined by the International Confederation of Thermal Analysis and Calorimetry (ICTAC) as "a gathering of the systems in which a property of an example is observed against time or temperature, while the temperature of the example, in a predetermined environment customized." The most well known method for application in the field of polymer is Differential scanning calorimetry (DSC) followed by TGA (along with its derivative DTGA).

DSC screens heat impacts related with stage changes and synthetic responses as a component of temperature. In DSC the distinction in heat flow to the sample and a reference at a similar temperature, is recorded as an element of temperature. The reference is an inactive material, for example, alumina, or only an unfilled aluminum pan. The temperature of both the example and reference are expanded at a steady rate. Since the DSC is at consistent pressure, heat flow is identical to enthalpy changes. In an endothermic procedure, for example, most stage advances, heat is consumed and, in this manner, heat flow to the example is higher than that to the reference. Henceforth dH/dt is positive. In an exothermic procedure, for example, crystallization, some cross-connecting forms, oxidation responses, and some deterioration responses, the inverse is valid and dH/dt is negative. Amid the warming of an example from room temperature to its disintegration temperature, tops with positive and negative dH/dt might be recorded; each peaks compares to a heat impact related with a particular procedure, for example, crystallization or liquefying. The inquiry emerges with respect to what sort of data is reachable from a DSC bend. The first and most direct data is the temperature at which a specific procedure happens, for instance, the softening purpose of a polymer. The temperature at which a response, for example, disintegration, may begin is another vital parameter. The peak temperature is related with the temperature at which most extreme response rate happens.

An extraordinary case in which the temperature of a stage change is of incredible significance in polymers is the glass transition temperature, T_g . This is a temperature at which nebulous (noncrystalline) polymers are changed over from a fragile, glasslike frame to a rubbery, adaptable shape. Over the glass change temperature certain segmental movements of the polymer are nearly unhindered by the connection with neighboring chains. Beneath the glass progress temperature, such movements are frustrated enormously and the unwinding times related with such upset movements are generally since quite a while ago contrasted with the length of the analysis. The agent meaning of glass transition temperature is that at this temperature, or inside a couple of degrees, the particular heat, the coefficient of heat development, the free volume and the dielectric steady (on account of a polar polymer) all change quickly. In the DSC explore, T_g is showed by an uncommon change in the standard, demonstrating an adjustment in the heat limit of the polymer. No enthalpy is related with such progress (for which reason it is additionally called a second request change), along these lines, the impact in a DSC bend is slight and is noticeable just if the instrument is sufficiently delicate. The second immediate data possible from DSC bends is the enthalpy related with specific procedures. DSC is a unique method for finding out about exothermic and endothermic procedures because of improvement of polymer chains on heating.

Thermogravimetry or thermogravimetric analysis (TGA) measures the mass loss of an example as the temperature of the example is expanded in a controlled way. One of the primary critical applications was the assurance of right drying temperature for encourages in gravimetric investigation. The second application was the distinguishing proof of the gases emitted while the example is warmed and the comparing weight reduction estimated. This data uncovers the thermo decay process and allows recognizable proof of the equation of the beginning material. TGA can likewise be utilized for the recognizable proof of mixes present in blends of materials. At the point when such blends are warmed the warm bend created comprises of all conceivable weight misfortunes from all parts present in the blend.

Thermal conductivity

The thermal conductivity (λ) is the amount of heat transported per unit time, through a unit area of a slab of material of unit length, per degree Kelvin of temperature difference between the two faces of the slab, at steady-state heat flow. Let

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q denote the heat flux in $J/(m^2.s)$ where m denotes meters. Let dT/dZ denotes the temperature gradient in Z -direction in Kelvin/m, and λ be expressed in units of $J/(K.m.sec)$. For unidirectional, rectilinear heat flow in Z -direction under steady-state conditions, λ is defined by equation-

$$q = -\lambda \cdot \frac{dT}{dZ} \quad \dots\dots(1.11)$$

It is useful to be able to estimate the thermal conductivities of polymers; both for optimizing certain processes and for evaluating end use performance.

During melt processing, for example by molding or extrusion, a polymer is first heated up, and then cooled, by a considerable amount in a short time period. The thermal conductivity is therefore very important in determining the optimum processing conditions. The motions of delocalized electrons play the key role in heat transfer in electrically conducting materials, such as metals. On the other hand, in insulators, such as ordinary organic polymers, electrons are localized in inner shell, lone pair and bonding orbitals. Therefore, heat transfer mainly occurs by atomic vibrations in organic polymers. For a given polymeric structure, the morphology (crystallinity and orientation), formulation (additives, fillers and impurities), humidity (especially for polar polymers), temperature and pressure, are the most important factors, which affect the thermal conductivity.

Optical Properties

Polymers have numerous vital optical properties, for example, the refractive record, reflection, scrambling, ingestion, clearness, shine, murkiness, birefringence, push optic coefficient, the yellowing prompted by photochemical debasement, and the particular refractive file augment in weaken arrangements. The optical properties of a polymer must be considered in assessing its potential handiness in a wide assortment of uses. Smaller circle coatings, focal points utilized in eye glasses, and certain sustenance and refreshment bundling materials are only a couple of precedents of such applications. The pressure optic coefficient is vital in deciding, regardless of whether a polymer will be valuable as a minimized plate covering. The optical clearness decides, regardless of whether a polymer can be utilized in focal points for eye glasses? Sturdiness is likewise critical in eye glass focal points, which for reasons of security must have the capacity to withstand an effect of extensive quality without shattering. The optical properties of a bundling material decide, regardless of whether the bundle will look alluring to a client and along these lines, help in the offer of its substance. The aggregate optical loss of a polymer must be decreased to the base sum feasible for the polymer to be conceivably valuable as an optical fiber material.

Antimicrobial properties

Polyaniline is a run of the mill phenylene based polymer having an artificially adaptable - NH-aggregate in the polymer chain flanked on either side by phenylene rings. The protonation, deprotonation and different other physico-synthetic properties of polyaniline are because of the nearness of this - NH-gathering. Polyaniline is not the same as other directing polymers in the three imperative perspectives (I) Charge conjugation in polyaniline isn't symmetric, that is, Fermi level and band hole are not framed in the focal point of the band and henceforth, valence band and conjugation groups are very uneven, (ii) Both carbon rings and nitrogen atoms are inside the conjugation way; this conjugation differs from polypyrrole, whose hetero particles don't contribute essentially to the π -bond arrangement and (iii) Electronic condition of the polyaniline can be changed through vibration of either the quantity of electrons or number of protons. An electroactive polymer, when oxidized or diminished, shows a huge change in characteristic electrical conductivity, e.g., polyaniline, polythiophene. These are otherwise called electroconductive polymer (EP)/conducting electroactive polymer (CEP). The soonest detailed use of conducting polymers (CPs) has been the utilization of unsupported polymers as sensor gadgets. Compound sensors are expository devices that proselyte the concoction potential vitality of a focused on analyte into a proportionate quantifiable flag, typically electrical or optical. There have been various audits on CPs with respect to their biomedical applications. The monetarily accessible solvent CPs polyaniline (PANI) united to lignin, poly(aniline sulphonic acid) and polypyrrole (PPy) are successful scroungers of the stable 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical. This property might be especially useful in tissues experiencing oxidative pressure, where the capacity to bring down the inordinate levels of responsive radical species is

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alluring. This free extreme lessening capacity of CPs is uncovered by productive rummaging of DPPH radicals, with two and four radicals searched per aniline or pyrrole monomer unit during the 30 min trial of the DPPH measure, demonstrating the potential for CPs to be successful cancer prevention agents when present in natural medium. The different vitamins and polyphenol free radical-rummaging cell reinforcements present in drinks, foods grown from the ground are right now of extraordinary enthusiasm, as these cell reinforcements may offer security against different sicknesses, for example, cardiovascular infections and cancer. The ES types of the copolymers have all the earmarks of being more successful than EB types of a similar copolymer. It creates the impression that the nearness of an acidic utilitarian gathering (-COOH) in the polymer chain enhances the antibacterial adequacy of the copolymer. Without being bound by hypothesis, the acidic dopants on the sub-atomic chains of copolymers may respond with the microorganisms (or other important microbial creature) which result in their demise. On the other hand, because of electrostatic adherence between copolymer atoms and the microscopic organisms, which convey charges of various extremity, the dividers of microorganisms may break and the substance of microbes end up uncovered or spill out, which influence the microscopic organisms to die [76]. The antimicrobial properties of conductive functionalized polyanilines have been researched by investigating their communication with bacterial cells. It has been seen that lower centralizations of PANI unequivocally hindered the development of wild sort *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* and in addition a few antimicrobial safe clinical pathogens. Nanofibres of polyaniline joined with fluconazole have been set up by basic and practical sol-gel technique utilizing D-10-camphorsulfonic corrosive (D-CSA) as a dopant and as a surfactant, and ammonium persulfate as the oxidant. The incorporated nano organized material was disintegrated in dimethylsulfoxide at various focuses and tried for its antifungal properties against *Candida albicans* (ATCC 140503), *Candida tropicalis* (ATCC 13803) and *Candida krusei* (ATCC 34135). The outcomes demonstrated that, contrasted with nanofiber organized leading PANI, polyaniline doped with fluconazole has indicated higher antifungal action on every one of the animal categories tried. It is particularly obvious that PANI doped fluconazole has extensive improved antifungal movement. *Candida tropicalis* is more helpless than *Candida albicans* and *Candida krusei* [77]. Polyaniline-Zr (IV) sulphosalicylate has likewise been tried against the different bacterial (*Escherichia coli*, *Bacillus thuringiensis* and *Pseudomonas aeruginosa*) and parasitic strains (*Aspergillus nigrus*, *Fusarium oxysporum* and *Penicillium chrysogenum*). Moderately higher exercises have been seen than the known antibiotics [78]. Polyaniline United Chitosan (Chit-g-PANI) has been screened for its antimicrobial movement against *Staphylococcus epidermidis*, *Staphylococcus aureus*, *Staphylococcus pyogenes*, *Escherichia coli*, *Candida albicans*, *Candida tropicalis* and *Candida krusei*. The aftereffects of antimicrobial movement of PANI and Chit-g-PANI were surveyed dependent on the normal width of zones of hindrance. The outcomes affirm that Chit-g-PANI has an upgraded antimicrobial movement contrasted with PANI. PANI and Chit-g-PANI additionally demonstrates a strong antifungal action when contrasted with antimicrobial activity [79]. The antibacterial properties of silver/poly(methyl methacrylate) (PMMA) nanofiber against both Gram negative (*Escherichia coli*) and Gram positive (*Staphylococcus aureus*) microorganisms were assessed utilizing least inhibitory focus (MIC) by the altered Kirby-Bauer strategy, and an active test. The MIC test showed that the silver/PMMA nanofiber had upgraded antimicrobial viability contrasted with that of silver sulfadiazine and silver nitrate at a similar silver concentration [80]. Boomi *et al.* [81] considered unblemished polyaniline (PANI), PANI-Ag, PANI-Au and PANI-Ag-Au nanocomposites. These have been effectively integrated by substance oxidative polymerization strategy utilizing aniline as monomer, ammonium persulfate as oxidant and metal (Ag, Au and Ag-Au) colloids. Perfect PANI, PANI-Ag, PANI-Au and PANI-Ag-Au nanocomposites were tried for antibacterial movement by agar well dissemination technique. PANI-Ag-Au nanocomposite showed higher antibacterial action against both Gram positive microbes [*Streptococcus sp.* (MTCC 890), *Staphylococcus sp.* (MTCC 96)] and Gram negative microscopic organisms [*Escherichia coli* (MTCC 1671) and *Klebsiella sp.* (MTCC 7407)] when contrasted and PANI-Ag nanocomposite, PANI-Au nanocomposite and perfect PANI. The curiosity of this examination is the polymer-bimetal union and its antibacterial potential. Hussaini and Eldars [82] announced about the copolymers of aniline and o-phenylenediamine/hydrophilic bentonite nanocomposites, which were integrated by 5:1 M proportions of the particular monomers with various rates of nanoclay by means of altered in situ substance copolymerization. The antibacterial exercises of PANI-o-PDA/bentonite nanocomposites towards both Gram positive and Gram negative microscopic organisms were explored. Lashkenari and Eisazadeh [83] detailed the examination which depicts the readiness of

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colloidal polyaniline/polyvinyl liquor (Skillet/PVA) nanocomposite by compound polymerization of aniline within the sight of ammonium peroxydisulphate as an oxidant and PVA as a stabilizer. The readied polymer was then tried for the antibacterial properties against Gram negative microbes: *Escherichia coli* and *Pseudomonas aeruginosa* and Gram positive microscopic organisms: *Staphylococcus aureus*. The antibacterial properties were surveyed by plate dissemination, least inhibitory focus (MIC), least bactericidal fixations (MBCs) and the bactericidal impact techniques. The outcomes unmistakably demonstrated that colloidal Container/PVA nanocomposite unequivocally hinders the development of wild sort *E. coli* (19 ± 0.5) mm pursued by *P. aeruginosa* (17 ± 0.5 mm) and *S. aureus* (17.5 ± 0.5 mm) microbes. *S. aureus* was totally executed after presentation for just 15 min, though *E. coli* was totally murdered after introduction for 25 min. Ma *et al.* [84] detailed the blend of graphene/zinc ferrite/polyaniline (GE/ZnFe₂O₄/PANI) composites, a sort of alluring photocatalytic inorganic antibacterial operator arranged through the in situ polymerization and portrayed by the cutting edge test advances. The antibacterial properties of the examples were examined against *Staphylococcus aureus*, *Escherichia coli* and *Candida albicans* under light. The outcomes demonstrated that the antibacterial action of the example was impacted by strain and the mass proportion of PANI to GE/ZnFe₂O₄ (mP/GZ) in the GE/ZnFe₂O₄/PANI composite. The example with mP/GZ of 0.6 had the best antibacterial action, and its base inhibitory fixation was 12.5 µg/mL for *Candida albicans*. In addition, the antibacterial systems were talked about. Boomi *et al.* [85] detailed the union of Pt colloid and Pt-Pd colloid, immaculate polyaniline, polyaniline/Pt nanocomposite and polyaniline/Pt-Pd nanocomposites. These were combined by straightforward concoction technique. The blended materials were assessed for antibacterial action, least inhibitory fixation and least bactericidal focus. The outcomes demonstrated that the nanocomposites showed enhanced antibacterial action when contrasted with perfect polyaniline and individual metal colloids. This is the principal give an account of the concoction union of polyaniline/Pt-Pd nanocomposite, which displays antibacterial movement at smaller scale molar fixation levels. Pathania *et al.* [86] combined polyaniline zirconium(IV) silicophosphate (PANI-ZSP) nanocomposite particle exchanger utilizing sol-gel technique by blending polyaniline (PANI) gel into the inorganic encourages of zirconium(IV) silicophosphate (ZSP). The PANI-ZSP nanocomposite particle exchanger was used as photocatalyst for remediation of methylene blue color from water. A debasement effectiveness of 82% was accomplished in two hours of presentation. Nanocomposite particle exchanger has been effectively utilized as antibacterial agent against *Escherichia coli*.

Despite everything it remains a test for the specialists to build up a productive nanocomposite having antimicrobial viability against wide range organisms including microbes, parasites and algal consortium, presenting genuine difficulties for the human survival. Looking to this part of nanomaterials Pramanik *et al.* [87] revealed the manufacture of bio-based hyperbranched poly(ester amide) (HBPEA)/polyaniline nanofiber changed montmorillonite (MMT) nanocomposites by an ex-situ polymerization strategy at fluctuated weight rates (1.0, 2.5, 5.0 wt.%) of the altered MMT (nanohybrid). Antimicrobial movement of the nanocomposites against a range of bacterial and contagious strains and in addition a consortium of algal animal groups alongside other wanted execution vouched them as intense antimicrobial materials in the domain of wellbeing and biomedical industry. Farias *et al.* [88] announced that thin half breed films made of polyaniline and the innovative artistic, titanium dioxide (TiO₂), arranged by the layer-by-layer (LbL) self-get together method. Intending to enhance the scattering of the fired in the polymer grid, the business surfactant, cetyl trimethyl ammonium bromide (CTAB), was utilized in the arrangement of the movies (**Figure 3**). The best state of testimony was discovered demonstrating synergic associations between the conjugated materials. The antibacterial action of the PANI (TiO₂)/CTAB films was contemplated and the gotten outcomes propose their utilization as antimicrobial coatings [90].

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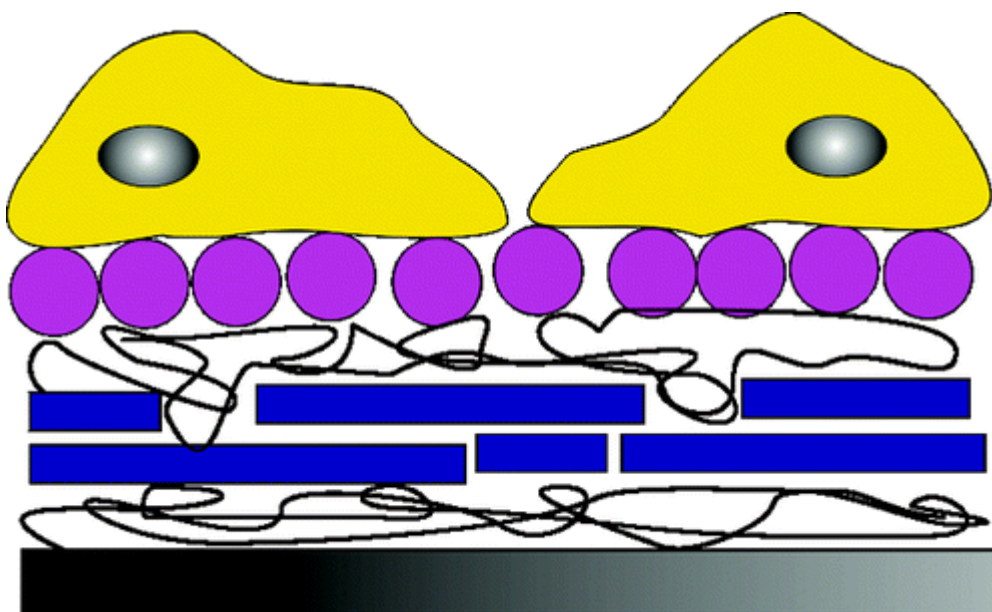


Fig. 3 – Layer –by-layer (LbL) assembly for antimicrobial properties of PANI (Kind permission of Reference 89)

Azo colors are known for their restorative significance and are all around perceived for their utilization as antineoplastics [91], antidiabetics [92] and antibacterial [93, 94]. They are known to be associated with various organic responses, for example, hindrance of DNA, RNA and protein combination, carcinogenesis and nitrogen fixation [95]. Azo colors are vital structures in the restorative and pharmaceutical fields [96] and it has been recommended that the azoimine linkage may be in charge of the organic exercises shown by some Schiff bases. What's more, Evans blue and Congo red azo colors have been examined as HIV inhibitors of viral replications. This impact is accepted to be caused by the effect of azo colors on both protease and reverse transcriptase of this virus [97]. The presence of an azo moiety in various kinds of mixtures has made them demonstrate antibacterial and antifungal activities. In the ongoing occasions, investigation of azo color as antimicrobial operators has gotten extensive attention [98]. Nonetheless, from the writing review, it has been seen that no consideration has been paid on the amalgamation and organic movement of color substituted polyanilines. The thought for the amalgamation of color subordinates of polyanilines risen by the verifiable truths about the restorative significance of polyanilines and number of colors. Along these lines, it should be examined about the organic action of color substituted polyanilines which ought to be more when contrasted with individual activities related with either polyaniline or colors.

IV. CONCLUSION

In this review article considerable attention has been paid on advancement in synthesis and properties of polyaniline in early years. This development in synthesis shows numerous changes in conducting nature, electrical, optical, thermal and antimicrobial properties. In recent years, high performance polymers have become important in the electronic industry, as encapsulants for electronic components, interlayer dielectrics and printed wiring board materials. Azo grafted polyaniline grafted shows their utilization as antineoplastics, antidiabetics, antiseptics, antibacterial and antitumor. The presence of an azo moiety in various kinds of mixtures has made them demonstrate antibacterial and antifungal activities. In the ongoing occasions, investigation of azo color as antimicrobial operators has gotten extensive attention. These properties of polyaniline certainly benefit the researcher working in day-to-day experimental work.

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