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# Reactive-Template Polymerization of Aniline, Pyrrole, and Indole on Amorphous Ce (IV) Phosphate with PTSA

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# بلمرة القوالب التفاعلية للأنيلين، البيرول، والإندول على فوسفات السيريوم *(IV)* غير المتبلور باستخدام *PTSA*

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**Abstract:**
Amorphous cerium (IV) hydrogen phosphate, $Ce(HPO_4)_2 \cdot 2.75H_2O$ (CePa), was synthesized and derived from chemical, XRD, and FT-IR. Novel CePa/polyaniline, polyindole, polypyrrole, and their PTSA-doped composites were synthesized via in-situ chemical oxidation of their corresponding monomer precursors. A plausible mechanism is part of CePa, acting as oxidizing agents for the monomers and their comonomers transformed to cerium (III) orthophosphate ($CePO_4$). CePa functions as a reactive support for the monomers and the comonomer polymerization agent. (CHNS) elemental analysis and FT-IR spectroscopy characterized the resultant novel conducting polymer and copolymer composites. The weight percentage of organic content from (CHNS) elemental analysis present in the novel CePa polyaniline, polyindole, polypyrrole, and composites are as follows: PANI 8.76 wt%, PPy 12.83 wt%, and PIn 39.85 wt%. The wt% of the CePa/PANI-co-PPy [(PANI 11.29%, PPy 3.98%)], PANI-co-PIn [(PANI 4.41%, PIn 7.10%)], and PIn-co-PPy [(PIn 40.26%, PPy 13.26%)]. The wt% of (PTSA) ranges from 1.64 to 4.04 wt%. Electrical conductivity of conducting polymers and copolymers measured at 25°C indicated the range within a semiconductor.

**Keywords:** Amorphous Cerium (IV) hydrogen phosphate; Polyaniline; Polypyrrole; Polyindole; Copolymer composites; Self-oxidative polymerization.

**الملخص:**
تم تحضير فوسفات السيريوم (IV) الهيدروجيني غير المتبلور، $Ce(HPO_4)_2 \cdot 2.75H_2O$ (CePa)، واستنتاج تركيبه من التحليل الكيميائي، وتحليل حيود الأشعة السينية(XRD) ، وطيف الاشعة تحت الحمراء (FT-IR) كما تم تحضير مركبات جديدة من CePaمع البولي أنيلين، البولي إندول والبولي بيرول، ومتراكباتها المشوبة بحامض بارا-تولوين سلفونيك (PTSA) عبر الأكسدة الكيميائية المباشرة في الموقع (In-situ) لمونومراتها الأولية. يتمثل أحد الآليات المحتملة في عمل CePa كعامل مؤكسِد للمونومرات والمونومرات المشتركة (Comonomers) وتحولها إلى أورثوفوسفات السيريوم الثلاثي (CePO4) حيث يعمل CePa كدعامات تفاعلية (Reactive support) للمونومرات وكعامل بلمرة للمونومرات المشتركة". وقد تم توصيف البوليمرات الموصلة الجديدة لمتراكبات البوليمرات والبوليمرات

المشتركة الناتجة عن طريق التحليل العنصري (CHNS) وطيف الأشعة تحت الحمراء (FT-IR) وتوضح النسب المئوية الوزنية للمحتوى العضوي الناتجة عن التحليل العنصري (CHNS) في متراكبات CePa الجديدة مع البولي أنيلين، البولي إندول، والبولي بيرول، كالتالي: البولي أنيلين (PANI): 8.76% وزناً، البولي بيرول (PPy): 12.83% وزناً والبولي إندول (PIn): 39.85% وزناً أما النسبة المئوية الوزنية لمتراكبات البوليمر المشترك CePa/PANI-co-PPy فكانت[(11.29% PANI , 3.98% PPy)] ولـ PANI-co-PIn كانت [(7.10% PIn , PANI 4.41%)] و لـ PIn-co-PPy كانت [(40.26% PIn , 13.26% PPy)] . كما تراوحت النسبة المئوية الوزنية لـ (PTSA) بين 1.64% و4.04% وزناً. وقد أشارت التوصيلية الكهربائية للبوليمرات والبوليمرات المشتركة الموصلة المقاسة عند 25 درجة مئوية إلى وقوعها ضمن نطاق شبه الموصل.

**الكلمات المفتاحية:** فوسفات السيريوم (IV) الهيدروجيني غير المتبلور، بولي أنيلين، بولي بيرول، بولي إندول، متراكبات البوليمرات المشتركة، البلمرة الذاتية المؤكسدة.

**Introduction:**

Tetravalent metal phosphates are characterized by their exceptional thermal stabilities, insolubility, and elevated ion-exchange potentials [1]. The compounds are present in amorphous and layered forms, particularly α and γ structures resembling clay minerals [3-5]. In general, these materials can be denoted by the formulas α-M(IV) $(HPO_4)_2 \cdot H_2O$, θ-M(IV) $(HPO_4)_2 \cdot 5H_2O$, and γ-M(IV). $PO_4$ (·) $H_2PO_4$ ($\cdot 2H_2O$.Particularly, cerium phosphates have been investigated for their ion-exchange utilities, although elaborating their specific structures proved challenging for a significant period [6-10]. Due to the structural composition and crystallinity of the consequential precipitates generated from the reaction between the Ce (IV) salt and the phosphoric acid of [$(PO_4)$/Ce (IV) percentage], this is significantly affected by the key experimental conditions, including the rate and order of the mixing protocol, agitation speed, temperature, and the duration of digestion [6-9].

Cerium (IV) hydrogen phosphates are commonly prepared via soft chemistry techniques, especially through the precipitation reaction of aqueous solutions of Ce (IV) salts with orthophosphoric acid or alkali phosphates.Electronically conducting polymers (ECPs), frequently termed 'synthetic metals,' illustrate organic polymers that conduct electricity. Those may have metallic conductivity or can be semiconductors, which has garnered significant scientific interest [11,12]. Due to their exceptional properties, ECPs are being utilized with increasing advanced technologies, including solar cells, sensing devices, energy storage systems, etc. Furthermore, their exclusive electrical and electrochemical profiles offer enormous potential for commercial implementations [13].

These materials are capable of being easily synthesized via chemical and electrochemical polymerization techniques [14, 15]. Among these techniques, chemical polymerization is preferred for industrial implementations due to its cost-effectiveness, high efficiency, and mass manufacturing compared to electrochemical methods. The main elements of this polymer family comprise polyaniline (PANI), polypyrrole (PPy), polyindole, polythiophene, and polycarbazole [16]. Notably, these polymers especially PANI show a controllable electrical conductivity in the doped state, excellent environmental stability, and unique non-redox doping by protonic acids.

There are many articles related to the synthesis of CPs doped with para-toluene sulfonic acid and their application in various fields [17, 18]. According to PTSA, it's not actually anchored to the CPs yet, only forming weak coordination bridges. The dopant's oxygen atom facilitates the coordination with the functional amine (-NH) groups inherent to the polymer's structure. [17,19].

**Materials and Methods:**

**Chemicals:**

Commercially accessible chemical substances were utilized without additional purifications. The precursor substances, comprising $Ce(SO_4)_2 \cdot 4H_2O$, $H_3PO_4$ (85%), and p-toluenesulfonic acid (PTSA), alongside solvents like dimethyl sulfoxide (DMSO), were procured from BDH. Further reagents, particularly $TiCl_4$, indole, and ethanol (95%), were obtained from Riedel-de Haën. High-purity monomers such as aniline (99.5% of Mindex UK) and pyrrole (Park). All remaining reagents possessed analytical purity.

**Instruments used for characterization:**

Structural characterization was conducted utilizing an X-ray Diffraction (XRD) diffractometer equipped, on a Siemens D-500, with Ni-filtered Cu Kα (λ=1.54056 Å), XRD by utilizing Cu Kα radiation at 1.540 Å as well as a Philips PW1710. The surface morphology was examined through Scanning Electron Microscopy (SEM) via a JOEL SMJ SM 5610 LV microscope. Functional categories were discerned utilizing Fourier to employ both Transform Infrared Spectrometer FT-IR, FT-IR-6100, and Shimadzu, (FT–IR) spectroscopy in the range 200–4000 $cm^{-1}$. Also, Carbon, Hydrogen, and Nitrogen (C, H, N) were determined utilizing Vario EL III automatic analyzer (Elemental, Germany), while pH measurements were conducted by WGW 521 pH Meter. Ultraviolet-Visible spectroscopy, Perkin Elmer

Life and Analytical Sciences, 710, Bridgeport Shelton, USA, and Conductivity Meter 4510 from JENWAY.

**Preparation of Amorphous Cerium (IV) Hydrogen Phosphate:**

A solution of 0.1 M cerium (IV) sulfate tetrahydrate (Ce $(SO_4)_2 \cdot 4H_2O$) in M $H_2SO_4$ (250 mL) was incrementally added to 125 mL of 0.1 M $NaH_2PO_4 \cdot 12H_2O$ in a 500 mL conical flask, with continuous agitation at ambient temperature (~23°C). Following the completion of the addition, stirring was sustained for 2 hours. The precipitated product was isolated by filtration and washed with purified water and acetone (filtrate pH ≈ 1.32). The result was subsequently redispersed in 100 mL of purified water, and the pH was corrected up to ≈ 2 using 2M NaOH. Ultimately, the solid was subjected to filtration and washed with water and acetone and subsequently air-dried.

**Estimation of water contents of amorphous cerium(iv) phosphate:**

0.1 grams of amorphous cerium (IV) phosphate was subjected to heating at 150°C. for 1.5 h. From the difference of weight % losses, the amount of moles of water content was estimated.

**polymerization of aniline, pyrrole and indole by CePa in presence of PTSA:**

Typically, an amorphous cerium (IV) hydrogen phosphate/polyaniline PTSA composite was prepared as follows: 0.3 g of CePa was mixed with 12 ml of aniline at room temperature (23°C) with stirring for 15 minutes, and then 0.3 g of PTSA in five mL of purified water was added. The stirring was persisted at room temperature for 24 hrs. The synthesized product was converted into a filtered, washed with purified water and ethanol, and then left to air-dry.

Following the same experimental conditions, polypyrrole PTSA and polyindole PTSA composites were prepared using 7.5 mL of 4% pyrrole in distilled water and 15 mL of 4% indole in (1:1 v/v), respectively, ethanol/purified water in the presence of 0.3 g of PTSA.

**Polymerization of the Comonomers Aniline-Pyrrole, Aniline-Indole and Indole-Pyrrole by CePa in Presence of PTSA:**

1. Amorphous cerium (IV) hydrogen phosphate/polyaniline-co-polypyrrole PTSA composite, 0.3 g CEPA, was prepared by mixing 6 ml 4% aniline and 4.5 mL 4% pyrrole in purified water at ambient temperature (23°C) with agitation for 15 min. To this, 0.3 g PTSA was added in 5 mL distilled water, and agitation at ambient temperature was continued for 24 hours. The precipitated product was isolated by filtration, washed with purified water and ethanol, and left to air-dry.
2. Amorphous cerium (IV) hydrogen phosphate/polyaniline-co-polyindole PTSA composite, 0.3 g CEPA, was prepared by mixing 6 ml 4% aniline and 7.5 mL 4% indole with a mixture of (1:1 v/v) purified/ethanol/water maintained at ambient temperature (23°C) with stirring for 15 min to dissolve 0.3 g in 5 mL purified water. Have PTSA. Further, shaking was continued for 24 hours at ambient temperature. The precipitated product was isolated by filtration, washed with purified water and ethanol, and left to air-dry.
3. Amorphous cerium (IV) hydrogen phosphate/polyindole-co-polypyrrole PTSA composites were prepared by mixing 0.3 g of CEPA with a mixture of 7.5 ml of 4% indole in (1:1 v/v) ethanol/distilled water and 4.5 mL of 4% pyrrole in purified water, agitation for 15 minutes at room temperature (23°C), until that 0.3 g was added. PTSA was added to 5 mL of purified water, and agitation was continued at room temperature for 24 hours. Thus, the obtained product was filtered, washed with purified water and ethanol, and then left to air-dry.

**Electrical Conductivity Measurements:**

Conductivity measurements were carried out at 25°C using the 4510-conductivity meter from JENWAY. **As follows:**

Dissolving 0.02 mg of the synthesized material (polymers or the copolymer composites) in 10 mL of DMSO. The instrument was calibrated in accordance with standard protocols. Subsequently, the conductivity cell was immersed in the solution, and measurements were recorded upon achieving stability. The cell was cleaned with deionized water between each sample to prevent contamination, it was agitated to eliminate internal droplets, and the outside was wiped prior to immersion in the subsequent sample with DMSO. Upon the conclusion of the experiments, the cell was thoroughly cleaned and stored. Likewise, the measurement protocols were executed on the remainder of the specimens.

**Results and Discussion:**

The physicochemical characterization validated the effective synthesis of amorphous cerium (IV) phosphate (CePa) with the formula Ce $(HPO_4)_2 \cdot 2.75H_2O$. Particularly, X-ray diffraction (XRD) patterns denote a lack of crystallinity, consistent with an amorphous phase. Additionally, thermal analysis permitted the accurate quantification of hydration water, and FT-IR spectra verified the existence of functional phosphate groups. Therefore, the ion exchange capacity (IEC) was assessed based on this structural verification.

**XRD of CePa:**

XRD of amorphous cerium (IV) phosphate was illustrated in Figure 1, illustrating a typical amorphous trend.

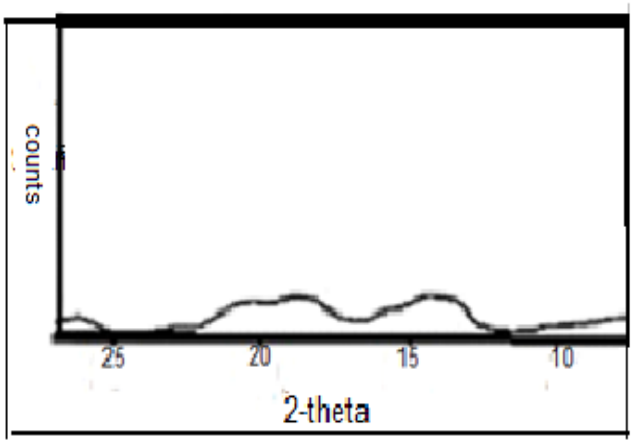


**Figure (1):** XRD of CePa.

**FT-IR of CePa:**

The spectral FT-IR of amorphous cerium (IV) phosphate in Figure 2 illustrates trends similar to those of other amorphous M(IV) phosphates. The spectrum features an extensive region located at 3100 $cm^{-1}$ corresponding to O-H of $H_2O$ stretching of water. The peak at~1550 $cm^{-1}$ is ascribed to H-O-H vibration, whereas the wide frequency range at~ 980 $cm^{-1}$ is associated with the vibrational modes of the phosphate $PO_4$ groups.

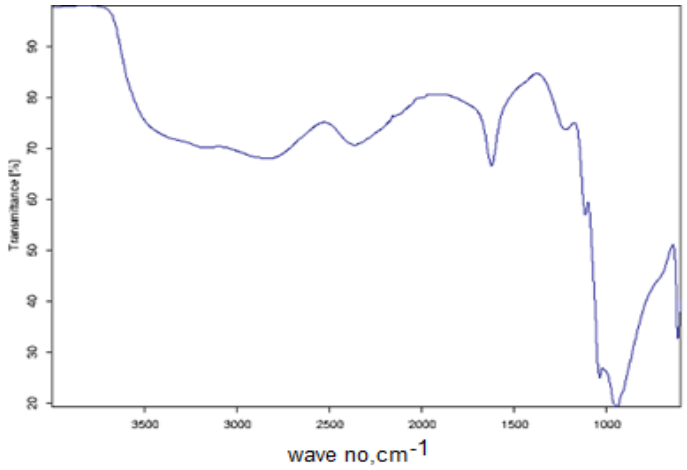


**Figure (2):** FT-IR Spectra of CePa.

**Exchange capacity of CePa:**

The ion exchange capacity (IEC) of CePa was evaluated via $Na^+$ titration. As illustrated in Figure 3, the titration curve indicates a capacity of ~5.5 meq/g.

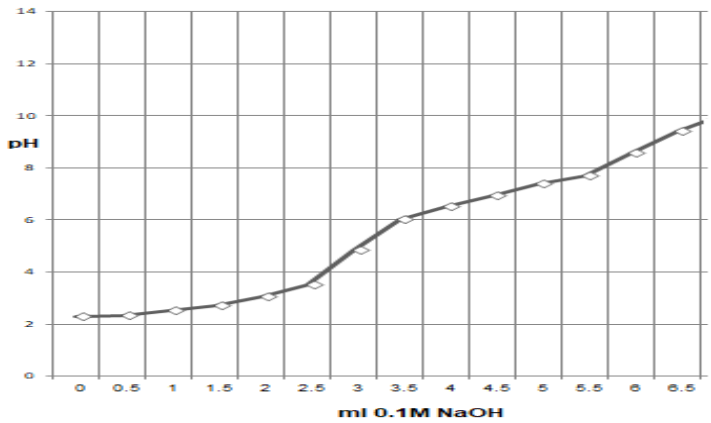


**Figure (3):** Na+ Titration Curve of CePa.

**Polymerization of Aniline, Pyrrole and Indole via CePa in Presence of Paratoluene Sulfonic Acid:**

Composites of CePa with polyaniline, polypyrrole, and polyindole were prepared via in-situ polymerization doped with PTSA. Characterization techniques included elemental analysis, FT-IR, UV-Vis, and SEM. Respectively, Elemental analysis (CHNS) conducted the polymer content in the composites, yielding weight percentages of 8.76% (PANI), 12.83% (PPy), and 39.85% (PIn).

**CePa-Initiated Oxidative Copolymerization of Aniline-Pyrrole, Aniline-Indole, and Indole-Pyrrole Systems in the Presence of PTSA:**

Copolymer composites based on CePa (CePa/PANI-co-PPy, CePa/PANI-co-PIn, and CePa/PIn-co-PPy) were synthesized via the reaction of their comonomers with CePa, and they were distinguished by elemental analysis (CHNS), UV-Vis, and FT-IR spectroscopy. According to (CHNS) element analysis, the (%wt) of the conducting copolymers were, for [PANI-PPy (PANI 11.29%, PPy 3.98%)], PANI-PIn [(PANI 4.41%), PIn (7.10%)] and PIn-PPy (PIn 40.26%), PPy (13.26%). From elemental CHNS analysis. The amount of paratoluene sulfonic acid found to be in the range of 1.65-4.0% in wt. was calculated based on the % wt. of sulfur contents, which ranged from 0.38 to 0.75% in wt. Polyindole-co-polypyrrole composite shows the highest content of PTSA (4.044% wt). Therefore, a decrease in sulfur concentration was observed. This trend suggests that PTSA was not covalently anchored to the CPs but was instead associated via weak coordination forces, typically as demonstrated in Figure 4. The sulfonate oxygen atoms of the dopant's coordination with the amine groups with functional properties (-NH) regarding the conducting polymer chain [17,19]. **Figure 4** illustrates the hypothetical molecular structure of the PIn-PPy/PTSA composites.

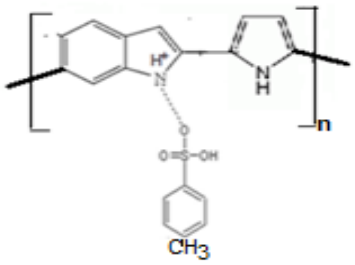


**Figure (4):** Molecular Structure of PIn-PPy / PTSA composites.

**FT-IR of CePa/ of Polyaniline, Polypyrrole and Polyindole PTSA Composites:**

FT-IR spectroscopy is a fundamental tool for investigating the structural properties of conductive polymers and their composites. As depicted in Figure (5), the spectral FT-IR of the resultant CePa/polyaniline, paratoluene sulfonic acid composites.

FT-IR spectra of the composite exhibited to follow the expected functional groups relating to the nature of the polymer structure. A flat, broad band in the range of 3600-3000 $cm^{-1}$ centered at approximately 3243 $cm^{-1}$ relates to N-H stretching vibration. Furthermore, the bands observed in the 2362-1900 $cm^{-1}$ region correspond to C-H interactions and are superimposed with characteristic bands of PTSA located at 2248 and ~1900 $cm^{-1}$ [20].

The spectral region between ~1850 and 1100 $cm^{-1}$ covers a band at 1509 $cm^{-1}$ that may be associated with S=O coupling interactions. The remaining characteristic bands in this region correspond to C-C, C-H bonds, C=C vibration, and C-N stretching of the polymer backbone. The broad absorption

centered at 995 $cm^{-1}$ confirms the presence of phosphate $PO_4$ vibrations. Additionally, the band at 841 $cm^{-1}$ corresponds to CH bonds, whereas the lower frequency bands in the range 687-564 $cm^{-1}$ are concerned with P=O stretching and $\delta(PO_4)$.

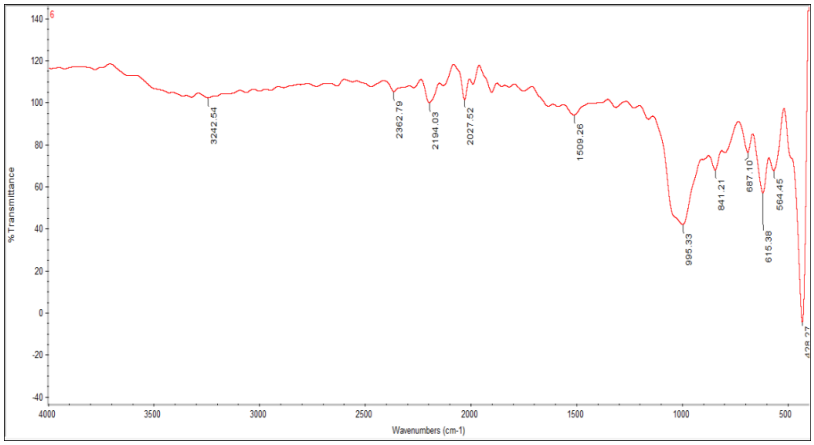


**Figure (5):** FT-IR Spectra of the Resultant CePa / PANI PTSA.

Figure (6) shows FT-IR spectra of the resultant CePa/polypyrrole, paratoluene sulfonic acid composites. It exhibits a flat broad band in the range of 3600-2800 $cm^{-1}$ centered at about 3125 $cm^{-1}$ related to N-H stretching vibration. The bands in the range 2100-1900 $cm^{-1}$ correspond to C-H bonds and are superimposed with characteristic bands of PTSA, which occur at ~1900 $cm^{-1}$ [20].

The band at 1625 $cm^{-1}$ may indicate the coupling of S=O; the rest of the bands in the region 1546-1125 correspond to C-C, C-H bonds, C=C aromatic vibration, and CN stretching of the polymer. The band at 1028 $cm^{-1}$ is assigned to $PO_4$ vibrations. A band at 812 $cm^{-1}$ corresponds to a CH bond. Bands in the range 682-611 $cm^{-1}$ are concerned with P=O stretching and $\delta(PO_4)$.

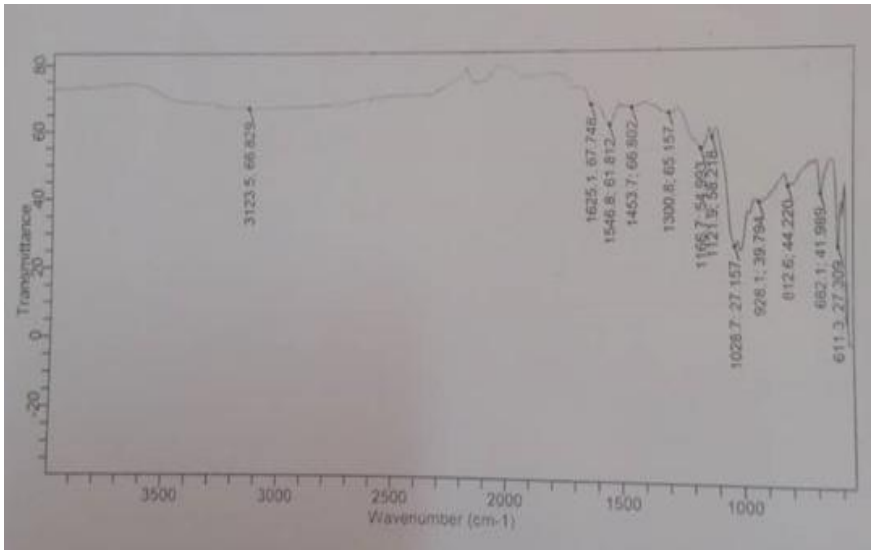


**Figure (6):** FT-IR Spectra of the Resultant CePa / Polypyrrole , Paratoluene Sulfonic Acid Composites

Figure (7) illustrates the spectral FT-IR of the resultant CePa/polindole, paratoluene sulfonic acid composites.

The spectral FT-IR of the composites exhibited the functional groups relating to the nature of the polymer. A flat, broad band in the range of 3724-3000 $cm^{-1}$ centered at about 3193 $cm^{-1}$ relates to N-H stretching vibration. In addition, bands observed in the range of 2374-1900 $cm^{-1}$ region corresponded to C-H interactions, which appeared superimposed with characteristic bands of the dopant PTSA located at 2248 and at ~1900 $cm^{-1}$ [20].

The spectral region between ~1850 and 1200 $cm^{-1}$ covers a band at 1670 $cm^{-1}$, which may be associated with S=O coupling interactions. Other characteristic bands in the region correspond to C-C and C-H bonds, C=C vibration, and CN stretching of the copolymer backbone. A small band

centered at ~1100 $cm^{-1}$ may be assigned to $PO_4$ vibrations. The band at 793 $cm^{-1}$ corresponds to the CH bond, while the bands in the range of 650-536 $cm^{-1}$ are attributed to the P=O stretching and δ($PO_4$) bending mode.

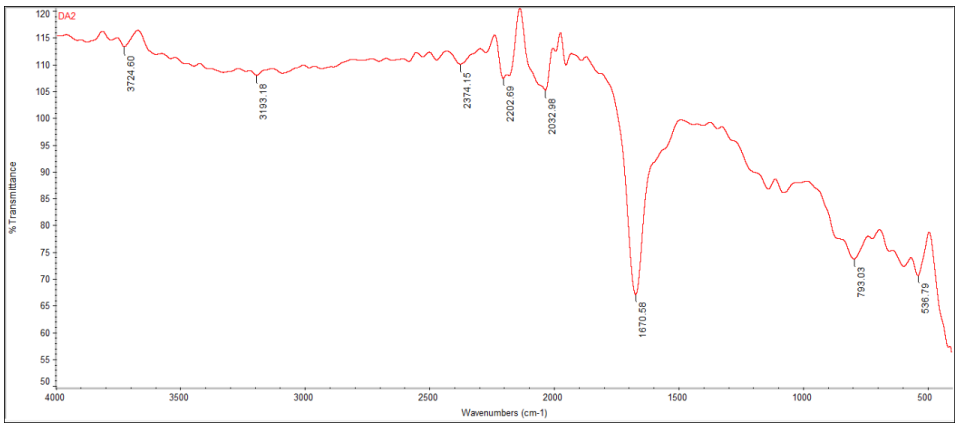


**Figure (7):** FT-IR Spectra of the Resultant CePa / PIn. PTSA.

**FT-IR of CePa/polyaniline-co-polypyrrole, polyaniline-co-polyindole, and polyindole-co-polypyrrole para-toluene sulfonic acid composites are shown in Figures (8-10):**

Figure (8) illustrates the FT-IR spectra of the resultant CePa/polyaniline-co-polypyrrole sulfonic acid composites. FT-IR spectra of the composites exhibit a similar trend of functional groups assigned to the nature of the copolymer. A flat, broad band in the range of 3700-3300 $cm^{-1}$ centered at about 3464 $cm^{-1}$ relates to N-H stretching vibration. The bands between 2236 and 1900 $cm^{-1}$ are associated with C-H bonds and are superimposed with characteristic bands of PTSA, which mainly occur at 2248 and at ~1900 $cm^{-1}$ [20].

Bands in the region ~1750-1200 $cm^{-1}$ covering a band at 1627 $cm^{-1}$ may indicate the coupling of S=O; the rest of the bands correspond to C-C, C-H bonds, C=C aromatic vibration, and CN stretching of the copolymer. Broadband centered at ~1004 $cm^{-1}$ assigned to $PO_4$ vibrations. A band at 700 $cm^{-1}$ corresponds to the CH bond; bands in the range 609-451 $cm^{-1}$ are concerned with P=O stretching and δ($PO_4$).

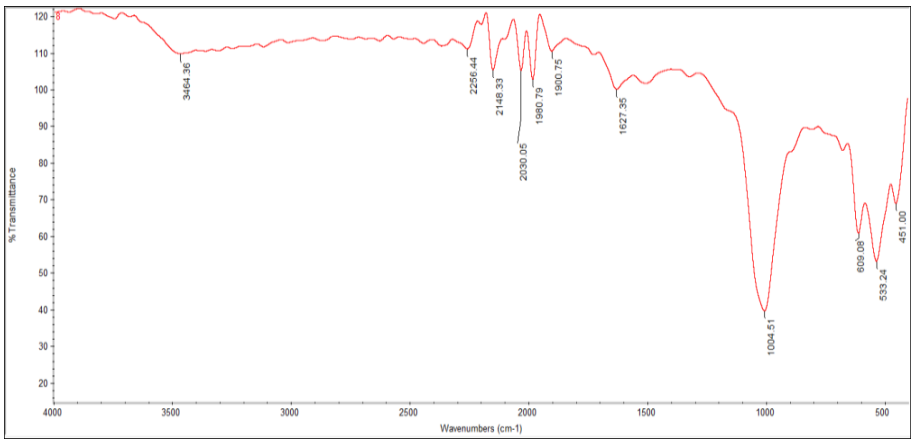


**Figure (8)**: FT-IR spectra of the resultant CePa / polyaniline-co-polypyrrole PTSA.

Figure (9) shows FT-IR spectra of the resultant CePa/polyaniline-co-polyindole para toluene sulfonic acid composite.

FT-IR spectra of the composite exhibited to follow the expected functional groups relating to the nature of the copolymer structure, where the flat broad band in the range of 3600-3100 $cm^{-1}$ centered at approximately 3337 $cm^{-1}$ relates to N-H stretching vibration. Furthermore, bands observed in the range 2351-1900 $cm^{-1}$ region correspond to C-H interactions, which appear superimposed with characteristic bands of the dopant PTSA located at 2248 and ~1900 $cm^{-1}$ [20].

The spectral region between ~18000 and 1200 $cm^{-1}$ covers a band at 1631 $cm^{-1}$, which may be associated with S=O coupling interactions. The remaining characteristic bands in this region correspond to C-C, C-H bonds, C=C vibration, and C-N stretching of the copolymer backbone. The broad absorption

centered at ~1006 $cm^{-1}$ confirms the presence of phosphate $PO_4$ vibrations. Additionally, the band at 745 $cm^{-1}$ corresponds to CH bonds, whereas the lower frequency bands 611-455 $cm^{-1}$ are associated with P=O stretching and δ($PO_4$).

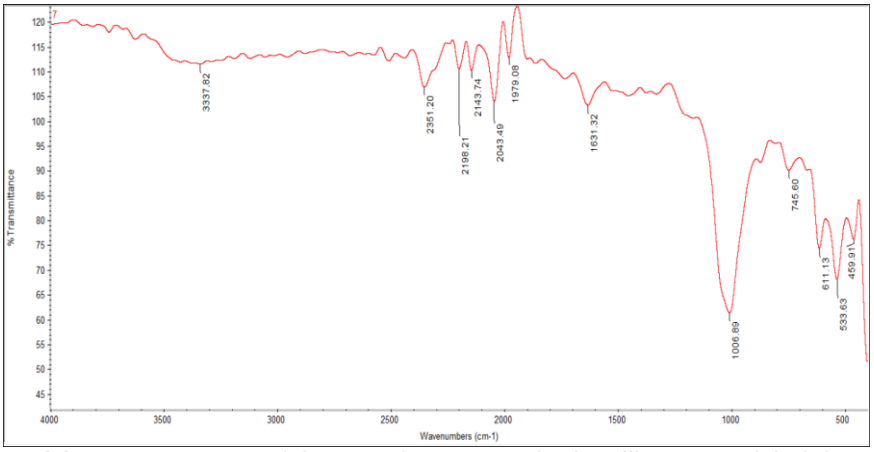


**Figure (9):** FT-IR Spectra of the Resultant CePa /Polyaniline-Co-Polyindole PTSA

FT-IR spectra of the composite exhibit almost expected functional groups relating to the nature of the copolymer structure. A flat, broad band in the range of 3600-3100 $cm^{-1}$ centered at about 3300 $cm^{-1}$ was assigned to N-H stretching vibration. Furthermore, the bands observed in the 2348-1852 $cm^{-1}$ were correspond to C-H interactions, which appear superimposed with characteristic bands of the dopant PTSA located at 2248 and ~1900 $cm^{-1}$ [20].

The spectral region between ~1800 and 1166 $cm^{-1}$ covers a band at 1600 $cm^{-1}$, which may be associated with S=O coupling interactions. The remaining characteristic bands in this region correspond to C-C, C-H bonds, C=C vibrations, and C-N stretching of the copolymer backbone. The broad absorption centered at ~1032 $cm^{-1}$ confirms the presence of phosphate $PO_4$ vibrations. Additionally, bands at 744 $cm^{-1}$ correspond to CH bonds, whereas the lower frequency bands in the range 680-448 $cm^{-1}$ are attributed to P=O stretching and δ($PO_4$).

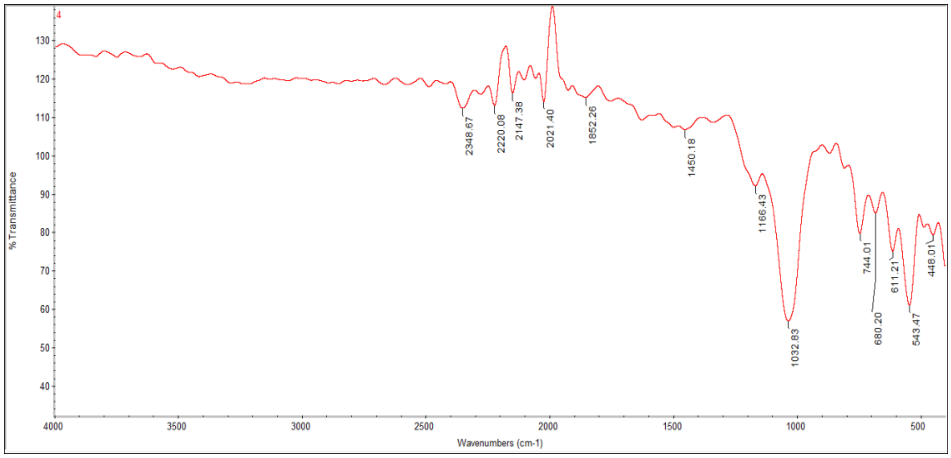


**Figure (10):** FT-IR Spectra of the Resultant CePa /Polyindole-Co-Polypyrrole PTSA.

**Electrical Conductivity DMSO-Soluble of Polyaniline, Polypyrrole, Polyindole and their Copolymers Composites:**

Electrical conductivity is a fundamental intrinsic property of materials. These materials vary widely from highly conductive metals to insulators such as glass and plastics. Solution conductivity quantifies the solution's capacity to transmit electrical current between two electrodes. Since charge transport is facilitated by ionic elements, a direct association exists between ionic concentration and conductivity levels. Practically, accurate measurements necessitate the input of certain cell constants into the meter either directly or via calibration to transform raw conductance data into precise conductivity values.

The electrical transport properties of the DMSO-soluble fractions comprising polyaniline, polypyrrole, polyindole, and their corresponding copolymers (CEPA-PTSA) copolymers were evaluated. Thus, the obtained conductivity values demonstrate that these composites exhibit semiconducting behavior.

**Table (1):** DC electrical conductivity of the synthesized homopolymers and copolymer composites

| Extracted CPs by DMSO | Conductivity ($Scm^{-1}$) |
|---|---|
| Pani | $1.0 \times 10^{-5}$ |
| PPy | $0.77 \times 10^{-5}$ |
| PIn | $4.20 \times 10^{-5}$ |
| Pani-co-PPy | $1.02 \times 10^{-5}$ |
| Pani-co-PIn | $1.92 \times 10^{-5}$ |
| PIn-co-PPy | $3.87 \times 10^{-5}$ |

The table outlines the electrical conductivity at room temperature of the DMSO-soluble fractions. Among the homopolymers, polyindole (PIn) demonstrated the greatest conductivity ($4.20 \times 10^{-5}$ $S \cdot cm^{-1}$), whereas polypyrrole (PPy) illustrated the lowest value ($0.77 \times 10^{-5}$ $S \cdot cm^{-1}$).

**Conclusion:**

In conclusion, amorphous cerium (IV) hydrogen phosphate $Ce(HPO_4)_2 \cdot 2.75\ H_2O$ (CePa) was successfully synthesized and distinguished via chemical, XRD, and FT-IR. A reactive template method was utilized to synthesize polyaniline, polypyrrole, polyindole, and their copolymers in the presence of PTSA, where part of the CePa host acted as an oxidizing agent, by the parent monomers and their comonomers, transformed to cerium (III) orthophosphate ($CePO_4$). Elemental analysis (CHNS) and FT-IR spectroscopy confirmed the successful synthesis of the (Ps) and(co-Ps) composites. PTSA functions as a dopant of CPs and co-CPs, where its sulfonate oxygen atoms coordinate with the amine (–NH) groups of the conducting polymer backbone. Finally, electrical conductivity measurements demonstrated that the synthesized composites exhibit semiconducting behavior at room temperature.

Author's contributions S.K. Shakshooki conceived of the presented idea, S.K. Shakshooki and F.A. Alakari were involved in planning and supervising the work. A.A. Jangher, R. M. Elhodiry, and S.Elfitori carried out the experiment. F.A. Alakari and R. M. Elhodiry wrote the manuscript with support from S.K. Shakshooki.

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