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Dielectric Performance of PVA/PPy Incorporating Copper Oxide Nanocomposite

Hayder H. Ahmed[1]
Department of Chemistry, College of Science,
University of Diyala, Diyala, Iraq.

Jinan Mohammed Mahmood[2]
Department of Chemistry, College of Science,
University of Diyala, Diyala, Iraq.

Zaid H. Mahmoud[3*]
Department of Chemistry, College of Science,
University of Diyala, Diyala, Iraq.

Corresponding Author:- Zaid H. Mahmoud[3*]

Abstract:- In this study, the films of PVA and CuO nanocomposite were synthesized using a simple solution casting technique. The produced films' optical and structural characteristics were thoroughly investigated. Copper oxide nanoparticles in 0.1–0.4 weight percent concentrations were implanted in the PVA film. Copper oxide nanoparticles were incorporated in polypyrrole and PVA host matrix to prepared films, as evidenced by X-ray diffraction (XRD) tests that revealed their existence in the PVA film without the emergence of extra impurity peaks. XRD tests verified the findings, which showed that the copper oxide nanoparticles belong to the monoclinic phase. The production of semicrystalline PVA polymer was reflected by the appearance of a peak at 2θ = 19.4°. The produced nanoparticles had an average crystallite size of roughly 0.52 nm. FTIR analysis was also employed to confirm the vibrational bands of the films. The findings also demonstrated that when the concentration of CuO nanoparticles increased, the dielectric characteristics improved because of the creation of polarization and an increase in the density of states. Additionally, it was noted that the development of charge transfer complexes caused the optical conductivity of the composite films to increase as the concentration of nanoparticles.

***Keywords**:- CuO Nanoparticles, PVA, XRD, Dielectric, Conductivity.*

I. INTRODUCTION

Because polymers have better optical and electrical qualities than traditional metals and alloys, materials experts from all around the world have recently been interested in them. The inclusion of nanoparticles is effectively facilitated by the polymer matrix, and the creation of nanocomposites increases the chemical and structural stability of the host polymeric material, hence improving its mechanical, optical, and electrical properties [1–10]. Because of their low cost, low density, great mechanical stability, and outstanding transparency, polymer nanocomposites are perfect hybrid materials for a variety of applications [11–15]. Because of their high electron affinity and ease of interaction with the surface groups of nanoparticles, polymers help create homogeneous nanocomposites [16–20]. This work used polyvinyl alcohol (PVA) as a host matrix to include nanofillers. PVA's low density (1.36 g/cm³), high melting point (230 °C), and water solubility make it an excellent matrix for charge storage. It is suitable for a range of applications due to its strong dielectric strength [21–28]. PVA is also used in solar cells because of its long carbon chain and hydroxyl group, which encourage the creation of hydrogen bonds. Polymer nanocomposites make it simple to study band gap variations and the electrical structure of amorphous and semi-crystalline materials. A wide range of automotive and aerospace applications use thermoplastic polymers, like PP and PA, because of their superior mechanical qualities, ease of processing, and affordability. However, these polymers could not be employed as structural materials due to their limited energy absorption capacity and poor impact resistance [29–40]. It is well known that simple metal oxides, such as those of zinc, copper, magnesium, and cerium, can change the structural, optical, and electrical properties of polymers [41–50]. According to recent research, copper oxide (CuO) nanoparticles' superior photocatalytic qualities make them an appropriate nanofiller for polymer composites. It has been observed that the utilization of nanoparticles in nano-emulsions or as nano-fertilizers increases the availability of micronutrients to plants, especially in the seedling stage. This increase in nutrient availability encourages plant development and lessens the need for fertilizers that are hazardous to the environment and include chemicals. Even at low concentrations, copper oxide nanoparticles (CuO-NPs) have been shown to promote growth and dry biomass in a variety of plant species. In order to improve seed vigor and germination potential, this study postulates that applying CuO-NPs to Lactuca sativa seedlings will increase nutrient bioavailability to the roots and other plant components. **[51-60].** CuO, a p-type semiconductor, is readily available and cost-effective, making it an ideal filler for nanocomposites. Its energy band gap ranges from 1.2 to 1.9 eV, and it possesses high dielectric permittivity and excellent insulating properties, making it suitable for various applications such as sensors, electrical, and optical devices [61-66]. Additionally, CuO demonstrates beneficial physical characteristics as photovoltaic, photoconductivity, spin dynamics, and superconductivity [67–73]. CuO nanoparticles have several

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uses, such as solar cells, batteries, and gas sensors. CuO is far less expensive than silver oxide and can be combined with polymers to create nanocomposites with the appropriate physical characteristics. In order to break down organic molecules, metal oxides such as ZnO, CuO, Fe2O3, TiO2, and SnO2 have recently been used as photocatalysts [74–80]. CuO-based photocatalysts' high adsorption coefficient, broad surface area, and chemical stability make them useful for treating wastewater and eliminating organic contaminants [81–86]. Farwa Mushtaq et al. [87] looked at the use of different polyvinyl alcohol-based adsorbents, including fibers, films, composite particles, and gels, to treat wastewater generated by the textile sector. PVA/CuO nanocomposite films' electrical and structural characteristics were documented by Jammula Koteswara Rao et al. [88]. The effects of zinc, copper, and graphene oxide nanofillers on the dielectric constant, dielectric loss, and AC conductivity characteristics of PVA-based composites were examined by Muhammad Aslam et al. [89]. The optical characteristics of mixed polyvinyl alcohol (PVA) nanocomposites were investigated by Omed Gh. Abdullah et al. [90]. The structural and thermal characteristics of pure ZnO, CuO, and nanofiller-doped PVA nanocomposite films were examined by Muhammad Aslam et al. [91]. CuO nanoparticles and PVA/CuO nanocomposites were synthesized and characterized by Alabur Manjunath et al. [92]. Using environmentally benign techniques, such as plant extracts like aloe vera, the authors of the current work created copper oxide nanoparticles and added them to the PVA matrix. The CuO nanoparticles had an average particle size of about 30 nm. The results of this study are innovative in comparison to earlier research since it presents green-synthesized CuO nanoparticles that are simple to manufacture in the lab. Along with optical properties like direct band gap, optical dielectric constant, optical dielectric loss, and optical conductivity, the authors also examined the β-phase, functional groups, vibrational modes, and Raman spectral analysis. They also used a single oscillator model to estimate the optical dispersion parameters of pristine PVA and PVA/CuO nanocomposites.

II. EXPERIMENTAL

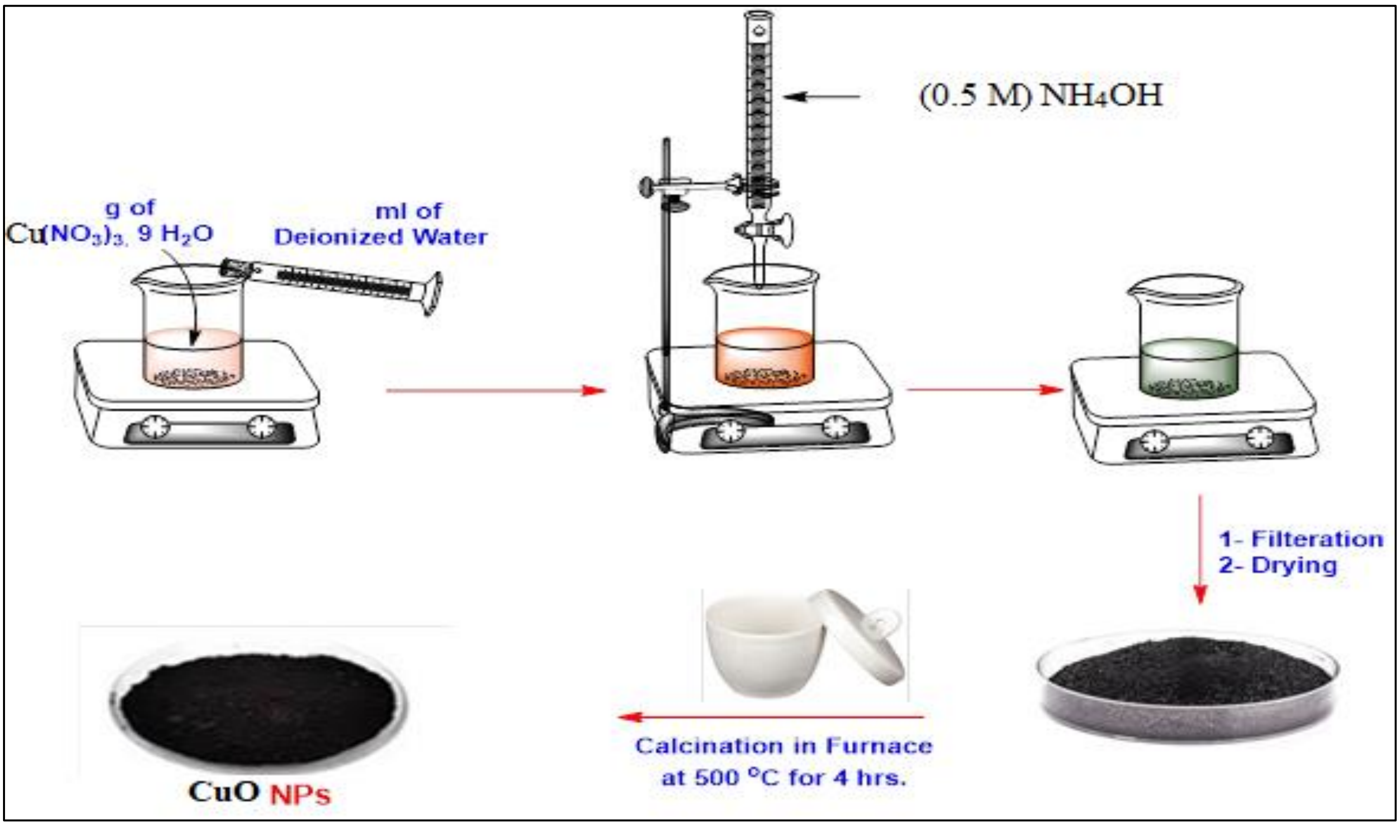
- *Chemicals:*

The study utilized solvents and chemicals obtained from different suppliers, including Riedel-de Haën, Sigma-Aldrich. These substances were used as received without undergoing any modification or purification.

- *Procedures:*

- *Preparation of Copper Oxide Nanoparticles (CuO NPs)*

A solution containing 1g of copper nitrate $Cu(NO_3)_2(H_2O)_3$ was prepared by dissolving it in 25 ml of distilled water. Subsequently, 3 ml of ethylene glycol ($C_2H_6O_2$) was added to the solution dropwise. Subsequently, the ammonia solution (0.5 M) NH_4OH was added at a frequency of one droplet per 30 seconds while stirring continuously at 60 °C. After adding three drops (24 ml) of the ammonia solution, a pH of 8 was obtained. The solution was then stirred for one hour and at 60 °C. Next, the solution underwent filtration to separate the desired substance, forming a precipitate. The precipitate was washed four times with distilled water and then air-dried. The solid was subsequently burned in a furnace at 500 °C. Scheme1.



Scheme (1): Schematic Diagram for the Preparation of CuO NPS

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- *Preparation of Pyrrole Polymer*

(3 ml) of pyrrole was mixed with (20 ml) of HCl acid (0.5M) in an ice bath. The mixture was then dropped by (2M, 20 ml) ammonium persulfate (APS). The black precipitate formed was placed in the refrigerator for 24 h. The product was then filtered and washed several times until the solution became transparent (PH=7).

- *Preparation of Polyvinyl Alcohol (PVA)*

A (2% w/v) PVA solution was prepared by dissolving 2g of PVA in 100 ml of distilled water under continuous stirring for 3h at 80 °C.

- *Preparation of Dielectric Materials Film*

Separately, (0.01 g) of PPy was ultrasonicated with 5 mL of ethanol to obtain a homogeneous solution. Then it was mixed with (5 mL, 2%) of PVA solution under strong stirring for 2 h. After that, the mixture was poured into a glass mold. Finally, it was left for 36 h to dry at room temperature before being taken for LCR measurement. The product was repeated with 0.01 g of CuO nanoparticles and after obtaining the result, several weights of it were taken (0.01, 0.02, 0.03, 0.04, 0.05) wt%) to find out which one is better.

III. RESULTS AND DISCUSSIONS

The FTIR of CuO is displayed in Figure 1. A peak at 3419 cm^{-1} wave number is associated with the O-H stretching of a hydroxyl group in the structure of copper oxide nanoparticles. A peak at 1612 cm^{-1} wave number is associated with the O–H bending of a hydroxyl group in the structure of a copper oxide nanoparticle. At 1376 cm^{-1} wave number, there is another peak connected to the C-O asymmetry in the copper oxide nanoparticle's structure. The C–O symmetry in the structure of the copper oxide nanoparticle is linked to the last peak, which is situated at wave number 1115 cm^{-1}. Finally, the peak is linked to the Cu–O bond and is situated at wave number 533 cm^{-1}. [93].

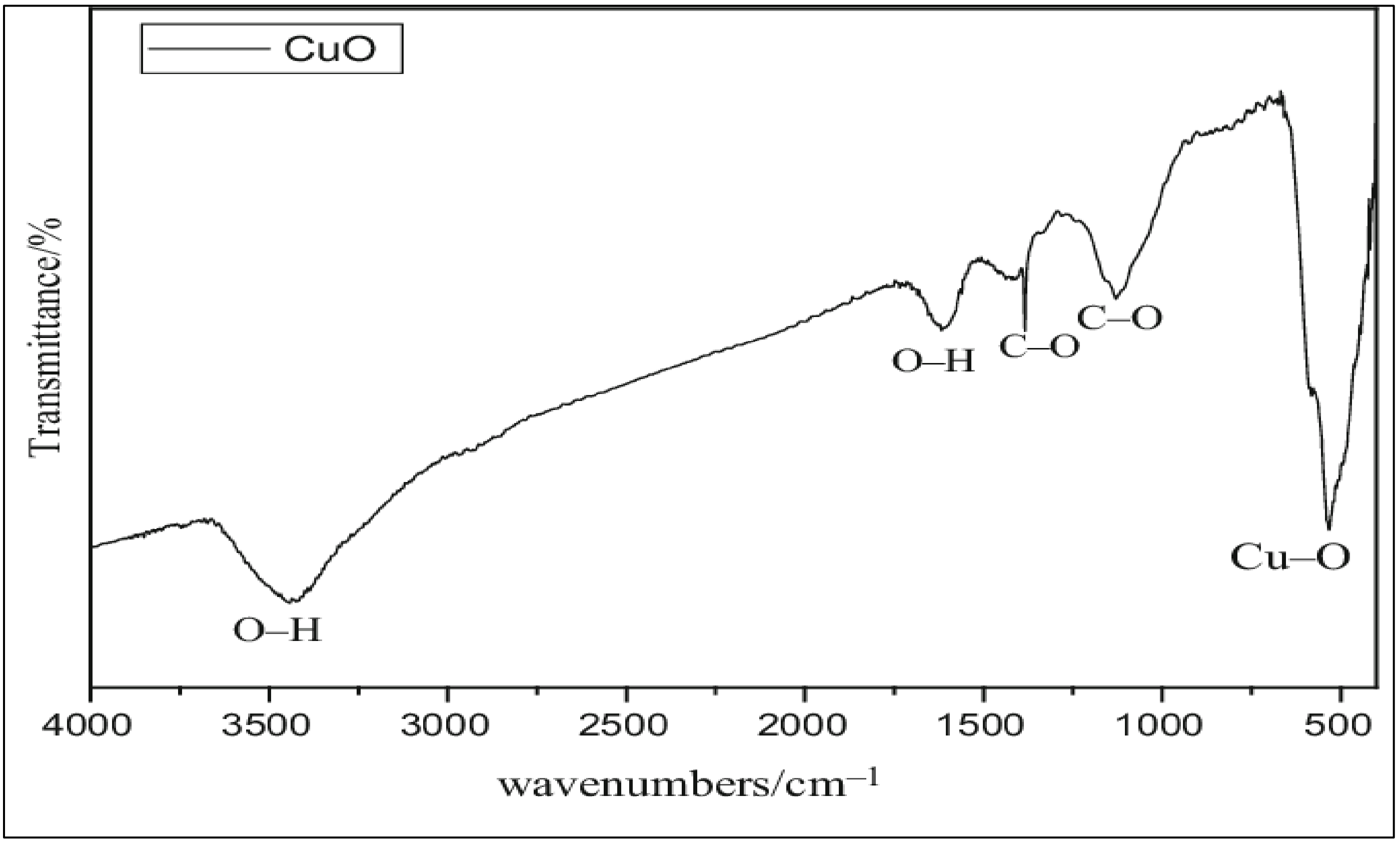

Fig 1 FTIR Spectrum of Cuo after Calcination.

Figure 2 displays the XRD pattern of copper oxide nanoparticles produced using a straightforward chemical process. The synthesis of copper oxide with monoclinic symmetry with lattice constant a = 4.683, b = 3.428, and c = 5.129 Å (JCPDS 80-1268) is confirmed by the appearance of XRD peaks at 2θ values of 32.53°, 35.63°, 38.74°, 48.83°, 53.56°, 58.36°, 61.51°, 65.85°, 66.42°, 68.11°, 72.34°, and 75.33° [94]. In the absence of any more addition, no extra peak resulting from the presence of any other phase was seen, indicating the creation of pure phase copper oxide nanoparticles. When Debye-Scherrer's formula was used to compute the average particle size of produced copper oxide nanoparticles, it was determined to be approximately 30 nm.

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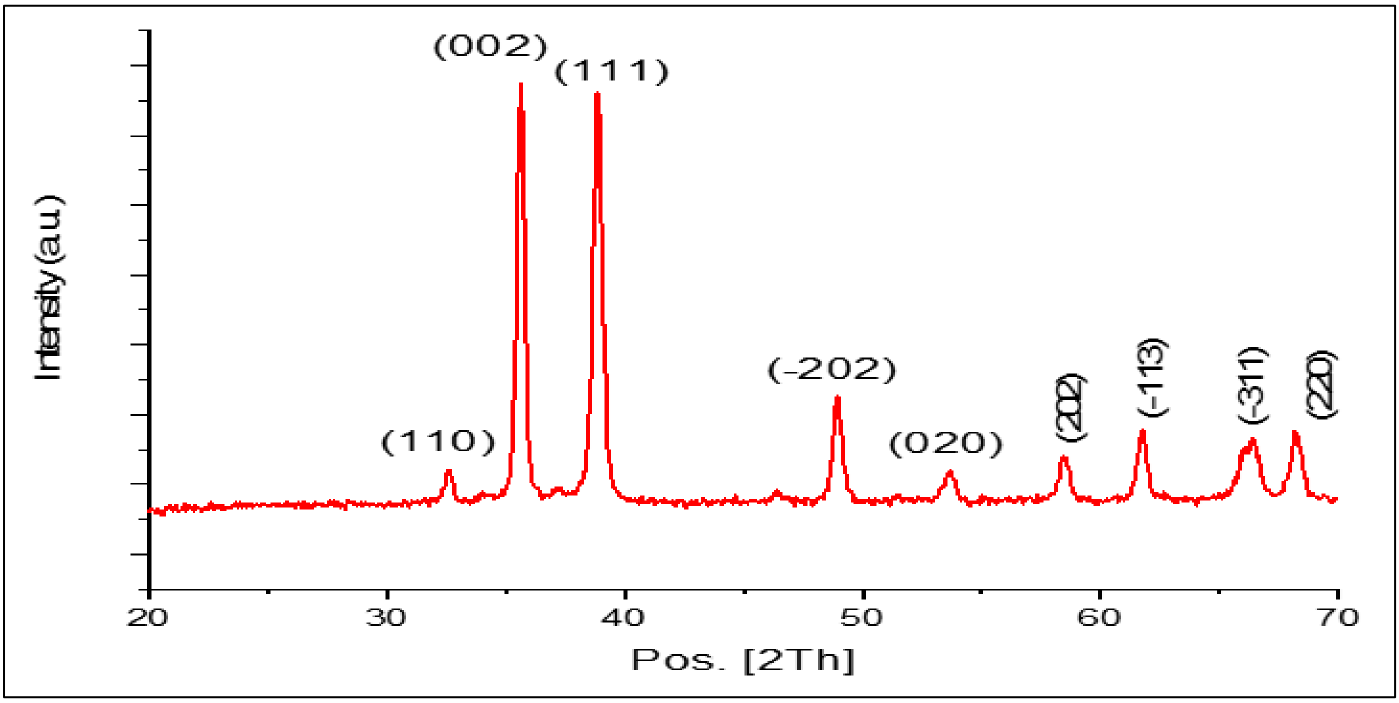

Fig 2 XRD of CuO Nanoparticles NPs

- *Scanning Electron Microscope (TEM):*

TEM examination was used to further establish the internal structure and to determine the particle size and shape accurately (Figure 3). The values for the average particle size and interplanar spacing agreed closely with the XRD results. However, the crystalline character of the artificial copper oxide nanoparticles is confirmed by the SAED pattern.

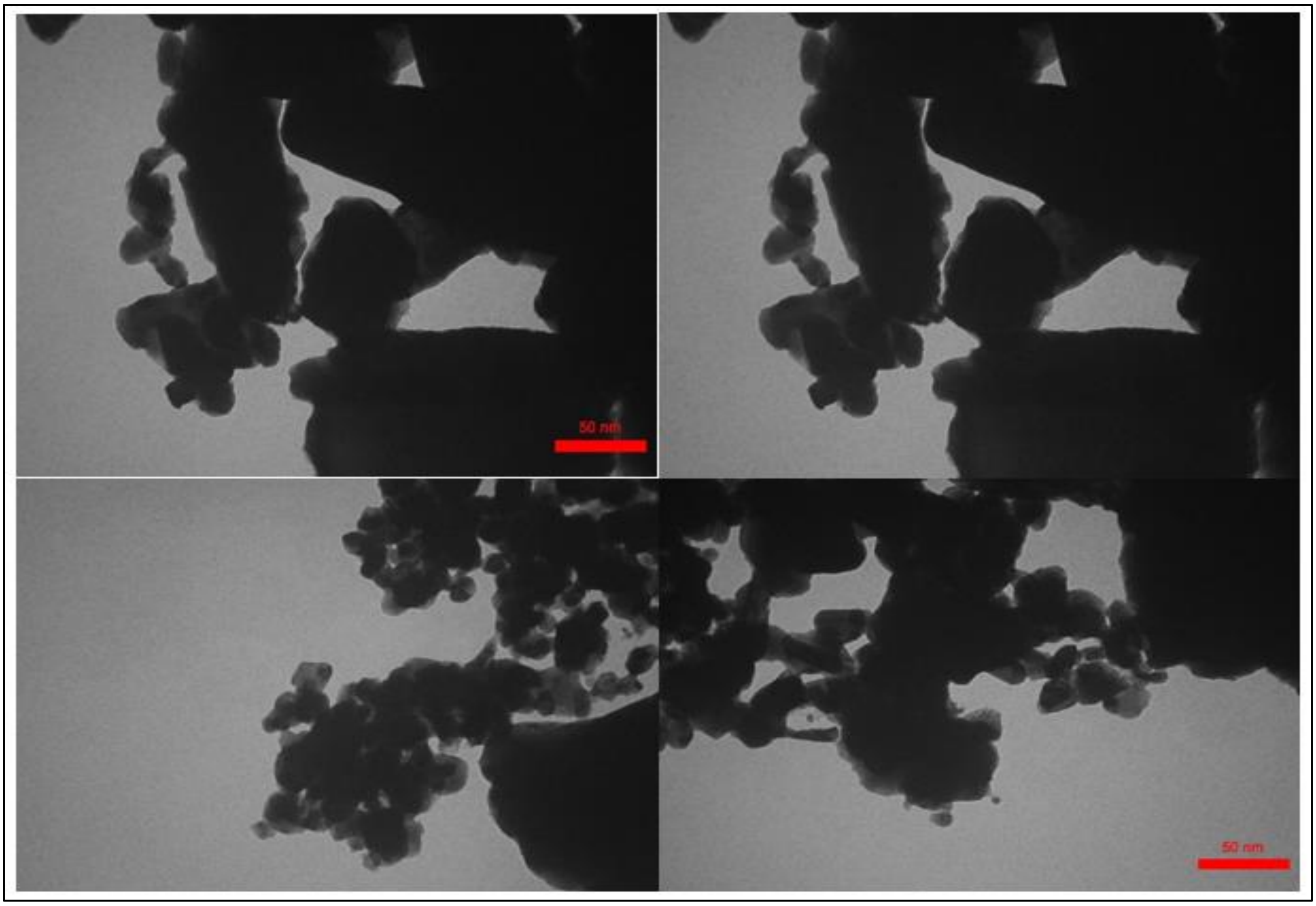

Fig 3 TEM of CuO Nanoparticles

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➢ *Electrochemical Properties*

- *Dielectric Constant*

Based on the connection, the dielectric constant was computed for pure PY, CuO, and Py-CuO membranes with weight ratios of 0.01–0.02, 0.03–0.04, and 0.05 weight percent at room temperature and in the frequency range of 50 Hz–5 MHz. Figure 4 shows that for all polymer composite membranes, the dielectric constant decreases slightly with increasing frequency. While dipolar groups in dielectric polymers can align themselves with the electric field at low frequencies, it is difficult for them to do so at large frequencies. At high frequencies, the time period is short and less than what molecules need to align themselves with the external field. In contrast to dipolar polarization, which takes a comparatively lengthy time in comparison to all polarization, electronic polarization happens fairly quickly yet takes longer than ionic polarization. This could be the cause of the dielectric constant values decreasing as frequency increases, and the decrease in charge space polarization could also be a contributing factor. Additionally, the picture shows that the dielectric constant value at the same frequency rises as the weight percentage of the supporting material (CuO) grows. This increase in polarizability is often responsible for this dielectric constant value [95–98]. In addition to the heterogeneous system, which is caused by the accumulation of some vacuum charges in the interfaces, the presence of CuO also contributes to the increase in the dielectric constant value at the same frequency by increasing the weight ratio. This results in the formation of interfaces in the polymer mixture, which raises the number of dipoles per unit volume [99,100].

Table 1 The Relationship between Frequency and Dielectric Constant

				Dielectric Constant (ε)			
Fr HZ	**py**	**CuO**	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**
102089.8	50.05252	50.05252	70.15113	71.5118	60.75757	65.59096	122.119
510249	49.58257	49.58257	59.40509	68.74674	57.01162	62.12917	110.444
1.02E+06	49.42683	49.42683	57.10452	68.38881	56.96791	61.50348	107.515
1.53E+06	48.96234	48.96234	55.2739	67.26858	56.44877	60.87506	105.4931
2.04E+06	49.39951	49.39951	55.21925	67.21393	56.50342	60.90238	104.81
2.55E+06	49.1536	49.1536	54.3176	66.96803	56.17555	60.49254	104.2636
3.06E+06	49.78203	49.78203	54.18099	67.24126	56.58539	61.17561	104.81
3.57E+06	49.59077	49.59077	54.20831	67.56913	57.76027	61.03899	105.0559
4.08E+06	50.4651	50.4651	54.12634	67.48716	57.62365	60.82041	105.3565
4.59E+06	49.64541	49.64541	53.90776	67.78771	57.62365	60.90238	105.9029
5.00E+06	51.61265	51.61265	55.2739	69.48172	59.01711	61.83135	107.7609

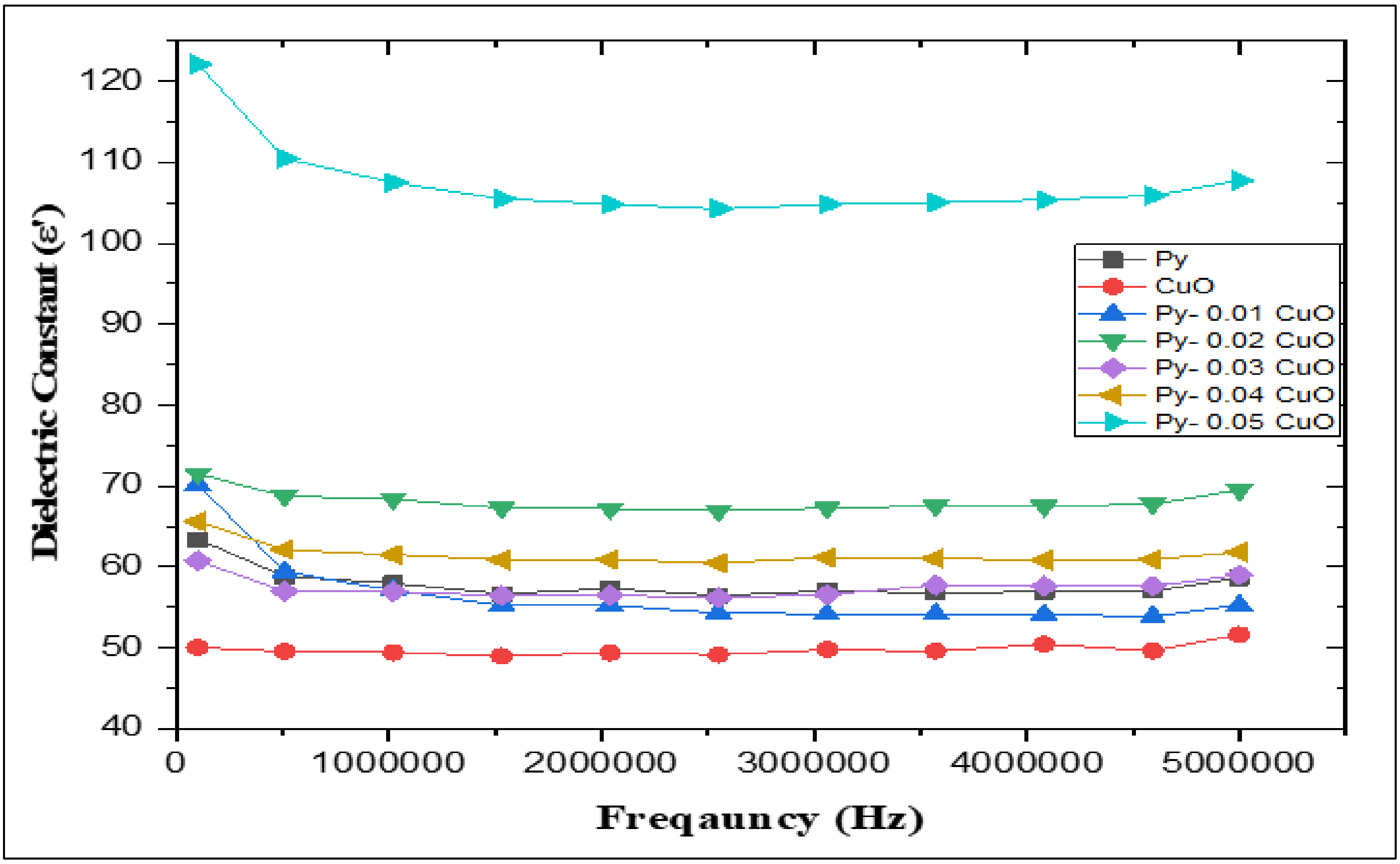

Fig 4 Dielectric Constant of CuO and CuO Doped Ppy

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- *Dissipation Factor*

The dielectric loss factor is the ratio of the power loss in dielectric materials to the total power transferred through the dielectric, the energy dissipation in dielectric materials is directly proportional to the dielectric loss factor, so knowing the value of this factor is of great benefit in applications of polymer composite membranes, as the dielectric loss factor was calculated for pure PY, pure CuO and Py-CuO polymer composite membranes with weight ratios of (0. 01, 0.02, 0.02, 0.03, 0.04, 0. 05 wt%). The dielectric loss factor decreases with increasing frequency for all polymer blend membranes at room temperature and within the frequency range of 50 Hz to 5 MHz, as shown in Figure (5). It is also evident that the dielectric loss factor values are high at low frequencies and then start to decrease as the frequency of the applied electric field increases. This is because of the enhancement of charge carriers that occurs across the width of the electric charge area, and the dielectric loss factor decreases at high frequencies until the electron energy equals the Fermi level. Another explanation for the frequency-dependent change in the dielectric loss factor is that the dipoles' energy is absorbed by the electric field in the system to overcome the resistance of the surrounding viscous materials during rotation. This absorbed energy decreases the amplitude of charge carriers moving between the boundaries as the frequency increases, meaning that the dipoles require more energy in the system to achieve relaxation, which results in a decrease in the dielectric loss factor. Additionally, the figure shows that as the weight percentage of the supporting material (CuO) grows, so does the dielectric loss factor value at the same frequency, and the percentage (0.05) of copper monoxide has the highest value, while the percentage (0.01) has the lowest. This is because the employing nanocrystals have more electrons, which raises the charge dipole and, in turn, increases electrical conductivity, which raises the value.

Table 2 Relationship between Dielectric Loss and Frequency

Fr HZ	py	CuO	0.01	0.02	0.03	0.04	0.05
102089.8	8.00525	0.84589	22.75703	4.2621	4.19835	3.8961	24.04523
510249	5.1194	1.55193	10.56817	3.32734	3.02162	3.55379	13.02134
1.02E+06	4.32544	1.85845	8.41721	3.13221	2.8313	3.29659	1.05E+01
1.53E+06	3.3147	1.038	6.8816	2.2535	2.09989	2.73938	9.13E+00
2.04E+06	2.76103	0.40508	6.02442	1.90215	1.72335	2.15594	8.16E+00
2.55E+06	2.94828	0.85036	5.70878	1.94207	1.70774	2.11119	7.93E+00
3.06E+06	2.69723	0.6621	5.81904	1.88276	1.53346	2.18397	7.53E+00
3.57E+06	2.43522	0.5455	4.85164	1.68923	1.91764	1.83727	7.56E+00
4.08E+06	2.16396	0.46933	4.64404	1.38349	1.33687	1.49618	7.41E+00
5.00E+06	0.90328	1.16128	3.21694	0.06253	0.51345	0.61213	6.41E+00

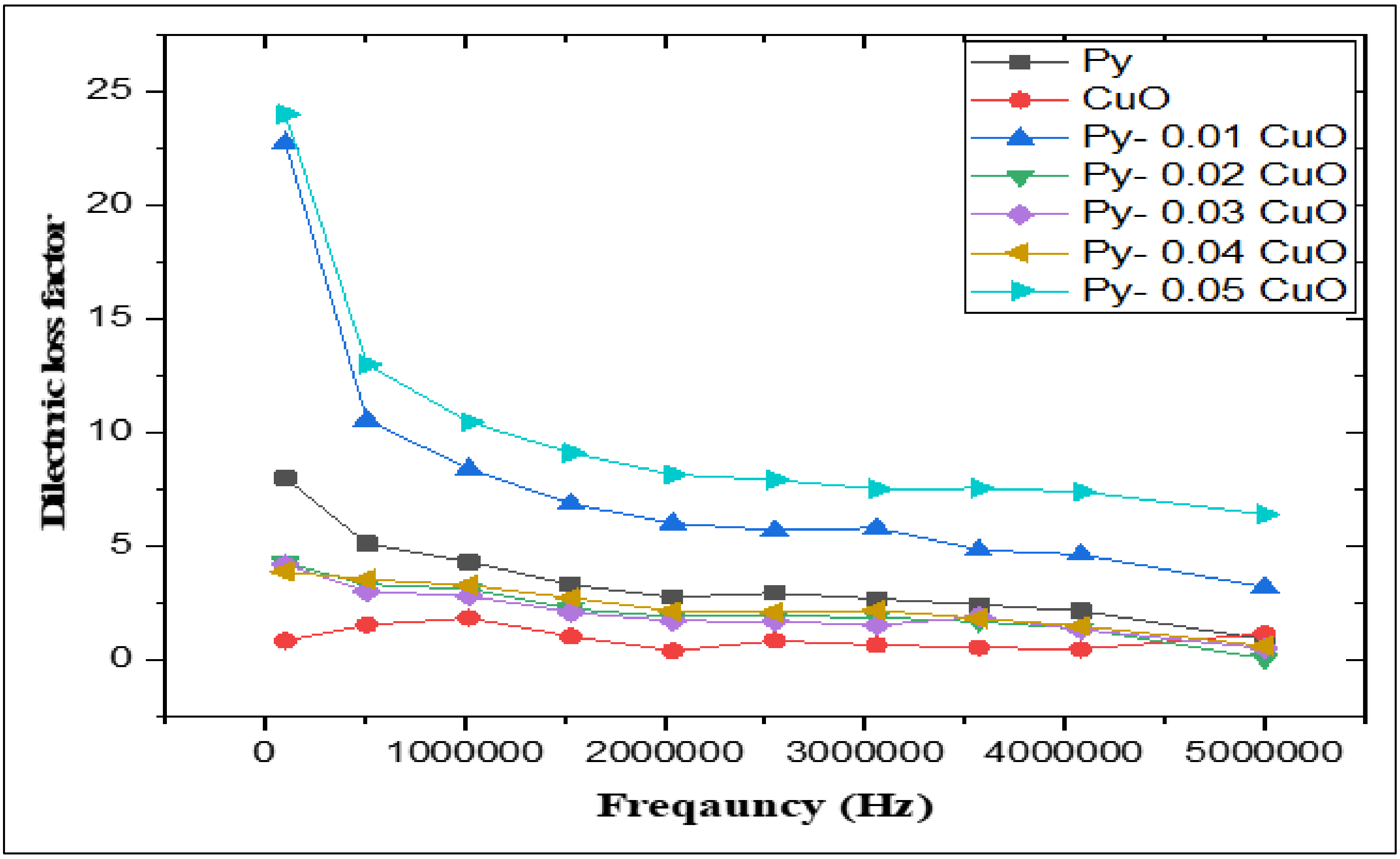

Fig 5 Dielectric Loss Constant of CuO and CuO Doped Ppy

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REFERENCES

[1]. Raya, I., Kzar, H. H., Mahmoud, Z. H., Al Ayub Ahmed, A., Ibatova, A. Z., & Kianfar, E. (2021). A review of gas sensors based on carbon nanomaterial. Carbon Letters, 1-26.

[2]. Bahadoran, A., Jabarabadi, M. K., Mahmood, Z. H., Bokov, D., Janani, B. J., & Fakhri, A. (2022). Quick and sensitive colorimetric detection of amino acid with functionalized-silver/copper nanoparticles in the presence of cross linker, and bacteria detection by using DNA-template nanoparticles as peroxidase activity. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 268, 120636.

[3]. Hsu, C. Y., Rheima, A. M., Kadhim, M. M., Ahmed, N. N., Mohammed, S. H., Abbas, F. H., ... & Kianfar, E. (2023). An overview of nanoparticles in drug delivery: properties and applications. South African Journal of Chemical Engineering.

[4]. Mahmoud, Z. H., AL-Bayati, R. A., & Khadom, A. A. (2022). The efficacy of samarium loaded titanium dioxide (Sm: TiO2) for enhanced photocatalytic removal of rhodamine B dye in natural sunlight exposure. Journal of Molecular Structure, 1253, 132267.

[5]. Sharaf, H. K., Salman, S., Abdulateef, M. H., Magizov, R. R., Troitskii, V. I., Mahmoud, Z. H., ... & Mohanty, H. (2021). Role of initial stored energy on hydrogen microalloying of ZrCoAl (Nb) bulk metallic glasses. Applied Physics A, 127, 1-7.

[6]. Kavitha, M., Mahmoud, Z. H., Kishore, K. H., Petrov, A. M., Lekomtsev, A., Iliushin, P., ... & Salmani, M. (2021). Application of steinberg model for vibration lifetime evaluation of Sn-Ag-Cu-based solder joints in power semiconductors. IEEE Transactions on Components, Packaging and Manufacturing Technology, 11(3), 444-450.

[7]. Raya, I., Widjaja, G., Mahmood, Z. H., Kadhim, A. J., Vladimirovich, K. O., Mustafa, Y. F., ... & Kafi-Ahmadi, L. (2022). Kinetic, isotherm, and thermodynamic studies on Cr (VI) adsorption using cellulose acetate/graphene oxide composite nanofibers. Applied Physics A, 128(2), 167.

[8]. Mahdi, M. A., Farhan, M. A., Mahmoud, Z. H., Rheima, A. M., sabri Abbas, Z., Kadhim, M. M., ... & Ismail, A. H. (2023). Direct sunlight photodegradation of congo red in aqueous solution by TiO2/rGO binary system: Experimental and DFT study. Arabian Journal of Chemistry, 16(8), 104992.

[9]. Hsu, C. Y., Mahmoud, Z. H., Abdullaev, S., Ali, F. K., Naeem, Y. A., Mizher, R. M., ... & Habibzadeh, S. (2024). Nano titanium oxide (nano-TiO2): a review of synthesis methods, properties, and applications. Case Studies in Chemical and Environmental Engineering, 100626.

[10]. Hsu, C. Y., Rheima, A. M., sabri Abbas, Z., Faryad, M. U., Kadhim, M. M., Altimari, U. S., ... & Kianfar, E. (2023). Nanowires properties and applications: a review study. South African Journal of Chemical Engineering.

[11]. Al-Salman, H. N. K., sabbar Falih, M., Deab, H. B., Altimari, U. S., Shakier, H. G., Dawood, A. H., ... & Kianfar, E. (2023). A study in analytical chemistry of adsorption of heavy metal ions using chitosan/graphene nanocomposites. Case Studies in Chemical and Environmental Engineering, 8, 100426.

[12]. Abdul-Reda Hussein, U., Mahmoud, Z. H., Alaziz, K. A., Alid, M. L., Yasin, Y., Ali, F. K., ... & Kianfar, E. (2023). Antimicrobial finishing of textiles using nanomaterials. Brazilian Journal of Biology, 84, e264947.

[13]. Mahmoud, Z. H., Barazandeh, H., Mostafavi, S. M., Ershov, K., Goncharov, A., Kuznetsov, A. S., ... & Zhu, Y. (2021). Identification of rejuvenation and relaxation regions in a Zr-based metallic glass induced by laser shock peening. Journal of Materials Research and Technology, 11, 2015-2020.

[14]. Al-Obaidi, N. S., Sadeq, Z. E., Mahmoud, Z. H., Abd, A. N., Al-Mahdawi, A. S., & Ali, F. K. (2023). Synthesis of chitosan-TiO2 nanocomposite for efficient Cr (VI) removal from contaminated wastewater sorption kinetics, thermodynamics and mechanism. Journal of Oleo Science, 72(3), 337-346.

[15]. Hsu, C. Y., Mahmoud, Z. H., Abdullaev, S., Mohammed, B. A., Altimari, U. S., Shaghnab, M. L., & Smaisim, G. F. (2023). Nanocomposites based on Resole/graphene/carbon fibers: a review study. Case Studies in Chemical and Environmental Engineering, 100535.

[16]. Jasim, S. A., Ali, M. H., Mahmood, Z. H., Rudiansyah, M., Alsultany, F. H., Mustafa, Y. F., ... & Surendar, A. (2022). Role of alloying composition on mechanical properties of CuZr metallic glasses during the nanoindentation process. Metals and Materials International, 28(9), 2075-2082.

[17]. sabah Ahmed, N., Hsu, C. Y., Mahmoud, Z. H., & Sayadi, H. (2023). A graphene oxide/polyaniline nanocomposite biosensor: synthesis, characterization, and electrochemical detection of bilirubin. RSC advances, 13(51), 36280-36292.

[18]. Fattahi, M., Hsu, C. Y., Ali, A. O., Mahmoud, Z. H., Dang, N. P., & Kianfar, E. (2023). Severe plastic deformation: Nanostructured materials, metal-based and polymer-based nanocomposites: A review. Heliyon.

[19]. Al-Salman, H. N. K., Hsu, C. Y., Jawad, Z. N., Mahmoud, Z. H., Mohammed, F., Saud, A., ... & Kianfar, E. (2023). Graphene oxide-based biosensors for detection of lung cancer: a review. Results in Chemistry, 101300.

[20]. Hameed Mahmood, Z., Riadi, Y., Hammoodi, H. A., Alkaim, A. F., & Fakri Mustafa, Y. (2023). Magnetic nanoparticles supported copper nanocomposite: a highly active nanocatalyst for synthesis of benzothiazoles and polyhydroquinolines. Polycyclic Aromatic Compounds, 43(4), 3687-3705.

ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14651233

[21]. Sabri Abbas, Z., Kadhim, M. M., Mahdi Rheima, A., jawad al-bayati, A. D., Talib Abed, Z., dashoor Al-Jaafari, F. M., ... & Kianfar, E. (2023). Preparing hybrid nanocomposites on the basis of resole/graphene/carbon fibers for investigating mechanical and thermal properties. BioNanoScience, 13(3), 983-1011.

[22]. Younus, L. A., Mahmoud, Z. H., Hamza, A. A., Alaziz, K. M. A., Ali, M. L., Yasin, Y., ... & Kianfar, E. (2023). Photodynamic therapy in cancer treatment: properties and applications in nanoparticles. Brazilian Journal of Biology, 84, e268892.

[23]. Jasim, S. A., Abdelbasset, W. K., Hachem, K., Kadhim, M. M., Yasin, G., Obaid, M. A., ... & Mahmoud, Z. H. (2022). Novel Gd2O3/SrFe12O19@ Schiff base chitosan (Gd/SrFe@ SBCs) nanocomposite as a novel magnetic sorbent for the removal of Pb (II) and Cd (II) ions from aqueous solution. Journal of the Chinese Chemical Society, 69(7), 1079-1087.

[24]. Mahmoud, Z. H., Falih, M. S., Khalaf, O. E., Farhan, M. A., & Ali, F. K. (2018). Photosynthesis of AgBr Doping TiO2 Nanoparticles and degradation of reactive red 120 dye. Journal of Advanced Pharmacy Education and Research, 8(4-2018), 51-55.

[25]. Alabada, R., Kadhim, M. M., sabri Abbas, Z., Rheima, A. M., Altimari, U. S., Dawood, A. H., ... & Kianfar, E. (2023). Investigation of effective parameters in the production of alumina gel through the sol-gel method. Case Studies in Chemical and Environmental Engineering, 8, 100405.

[26]. Bokov, D. O., Mustafa, Y. F., Mahmoud, Z. H., Suksatan, W., Jawad, M. A., & Xu, T. (2022). Cr-SiNT, Mn-SiNT, Ti-C70 and Sc-CNT as effective catalysts for CO2 reduction to CH3OH. Silicon, 14(14), 8493-8503.

[27]. Alkhawaldeh, A. K., Rheima, A. M., Kadhim, M. M., sabri Abbas, Z., Abed, Z. T., mohamed dashoor Al-Jaafari, F., ... & Mahmoud, Z. H. (2023). Nanomaterials as transmitters of non-viral gene vectors: A review. Case Studies in Chemical and Environmental Engineering, 8, 100372.

[28]. Mahmoud, Z. H., Hamrouni, A., Kareem, A. B., Mostafa, M. A., & Majeed, A. H. (2023). Synthesis and characterization of chitosan sheet modified by varied weight ratio of anatase (TiO2) nano mixture with Cr (VI) adsorbing. Kuwait Journal of Science, 50(3), 290-299.

[29]. Mahmoud, Z. H. (2017). The magnetic properties of alpha phase for iron oxide NPs that prepared from its salt by novel photolysis method. Journal of Chemical and Pharmaceutical Research, 9(8), 29-33.

[30]. Farhan, M. A., Mahmoud, Z. H., & Falih, M. S. (2018). Synthesis and characterization of TiO2/Au nanocomposite using UV-Irradiation method and its photocatalytic activity to degradation of methylene blue. Asian J. Chem, 30(5), 1142-1146.

[31]. Hsu, C. Y., Rheima, A. M., Mohammed, M. S., Kadhim, M. M., Mohammed, S. H., Abbas, F. H., ... & kianfar, E. (2023). Application of carbon nanotubes and graphene-based nanoadsorbents in water treatment. BioNanoScience, 13(4), 1418-1436.

[32]. Hsu, C. Y., Ajaj, Y., Mahmoud, Z. H., Ghadir, G. K., Alani, Z. K., Hussein, M. M., ... & Kareem, A. H. (2024). Adsorption of heavy metal ions use chitosan/graphene nanocomposites: A review study. Results in Chemistry, 101332.

[33]. Mahmoud, Z. H., Salman, H. A., Hussein, H. H., Adhab, A. H., Al-Majdi, K., Rasheed, T., ... & Kianfar, E. (2023). Organic chemical Nano sensors: synthesis, properties, and applications. Brazilian Journal of Biology, 84, e268893.

[34]. Jasim, S. A., Jabbar, A. H., Bokov, D. O., Al Mashhadani, Z. I., Surendar, A., Taban, T. Z., ... & Mustafa, Y. F. (2023). The effects of oxide layer on the joining performance of CuZr metallic glasses. Transactions of the Indian Institute of Metals, 76(1), 239-247.

[35]. Ajaj, Y., Al-Salman, H. N. K., Hussein, A. M., Jamee, M. K., Abdullaev, S., Omran, A. A., ... & Mahmoud, Z. H. (2024). Effect and investigating of graphene nanoparticles on mechanical, physical properties of polylactic acid polymer. Case Studies in Chemical and Environmental Engineering, 9, 100612.

[36]. Mansoor Al Sarraf, A. A., H. Alsultany, F., H. Mahmoud, Z., S. Shafik, S., I. AI Mashhadani, Z., & Sajjadi, A. (2022). Magnetic nanoparticles supported zinc (II) complex (Fe3O4@ SiO2-Imine/Thio-Zn (OAc) 2): a green and efficient magnetically reusable zinc nanocatalyst for synthesis of nitriles via cyanation of aryl iodides. Synthetic Communications, 52(9-10), 1245-1253.

[37]. Raya, I., Mansoor Al Sarraf, A. A., Widjaja, G., Ghazi Al-Shawi, S., F Ramadan, M., Mahmood, Z. H., ... & Ghaleb Maabreh, H. (2022). ZnMoO4 nanoparticles: novel and facile synthesis, characterization, and photocatalytic performance. Journal of Nanostructures, 12(2), 446-454.

[38]. Rheima, A. M., sabri Abbas, Z., Kadhim, M. M., Mohammed, S. H., Alhameedi, D. Y., Rasen, F. A., ... & Kianfar, E. (2023). Aluminum oxide nano porous: Synthesis, properties, and applications. Case Studies in Chemical and Environmental Engineering, 8, 100428.

[39]. Chupradit, S., Raya, I., Ngoc Huy, D. T., Bokov, D., Van Tuan, P., Surendar, A., ... & Sajjadifar, S. (2021). Role of Glass Composition on Mechanical Properties of Shape Memory Alloy-Metallic Glass Composites. Advances in Materials Science and Engineering, 2021(1), 4775793.

[40]. Jasim, S. A., Ali, S. A. J., Fadhil, O. Q., Rakhmatova, M. K., Kzar, H. H., Margiana, R., ... & Sultan, M. Q. (2023). Investigating the effects of hydro-alcoholic urtica dioica extract and retinoic acid on follicular development: an animal study. Medical Journal of the Islamic Republic of Iran, 37.

ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14651233

[41]. Siswanto, W. A., Romero-Parra, R. M., Sivaraman, R., Turki Jalil, A., Gatea, M. A., Alhassan, M. S., & Mahmoud, Z. H. (2023). The characterization of plastic behavior and mechanical properties in the gradient nanostructured copper. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 237(9), 1910-1920.

[42]. Mahmoud, Z. H., Kareem, N. F. A., & Kareem, A. A. A. (2018). Effect of solvents on size of copper oxide nanoparticles fabricated using photolysis method. Asian J. Chem, 30, 223-225.

[43]. Jimaa, R. B., & Mahmoud, Z. H. (2018). Evaluation the Efficiency of $CuFe_2O_4$ Prepared Photolysis by OSD and Photo degradation. Entomology and Applied Science Letters, 5(2-2018), 91-100.

[44]. Pallathadka, H., Mohammed, H. K., Mahmoud, Z. H., Ramírez-Coronel, A. A., Altalbawy, F. M., Gatea, M. A., & Kazemnejadi, M. (2023). Ultrasound-promoted metal-free homogenous olefins epoxidation and direct conversion of alkenes to cyclic carbonates using catalytic TAIm [X](X= WO42-, HSO5-) recyclable ionic liquid under mild conditions. Inorganic Chemistry Communications, 154, 110944.

[45]. Mahmoud, Z. H., & Khudeer, R. F. (2019). Spectroscopy and structural study of oxidative degradation Congo Red Dye under sunlight using TiO2/Cr2O3-CdS nanocomposite. International journal of chemtech research, 12(3), 64-71.

[46]. Hamid, Z. (2017). Synthesis of bismuth oxide nano powders via electrolysis method and study the effect of change voltage on the size for it. Australian journal of basic and applied sciences, 11(7), 97-101.

[47]. Mahmoud, Z. H., Ajaj, Y., Hussein, A. M., Al-Salman, H. N. K., Mustafa, M. A., Kadhum, E. H., ... & Kianfar, E. (2024). CdIn2Se4@ chitosan heterojunction nanocomposite with ultrahigh photocatalytic activity under sunlight driven photodegradation of organic pollutants. International Journal of Biological Macromolecules, 267, 131465.

[48]. Raya, I., Widjaja, G., Hachem, K., MN, R., Ahmed, A. A., M Kadhim, M., ... & Aravindhan, S. (2021). MnCo2O4/Co3O4 nanocomposites: microwave-assisted synthesis, characterization and photocatalytic performance. Journal of Nanostructures, 11(4), 728-735.

[49]. Jameel, M. K., Mustafa, M. A., Ahmed, H. S., jassim Mohammed, A., Ghazy, H., Shakir, M. N., ... & Kianfar, E. (2024). Biogas: Production, properties, applications, economic and challenges: A review. Results in Chemistry, 101549.

[50]. AbdulKareem, E. A., Mahmoud, Z. H., & Khadom, A. A. (2023). Sunlight assisted photocatalytic mineralization of organic pollutants over rGO impregnated TiO2 nanocomposite: Theoretical and experimental study. Case Studies in Chemical and Environmental Engineering, 8, 100446.

[51]. Mahmoud, Z. H. (2019). Photodegradation of methylene blue solution via au doped TiO2 nanocomposite catalysts prepared using novel photolysis method. Iranian Journal of Chemistry and Chemical Engineering (IJCCE), 38(2), 29-35.

[52]. Mohammed, L. A., Farhan, M. A., Dadoosh, S. A., Alheety, M. A., Majeed, A. H., Mahmood, A. S., & Mahmoud, Z. H. (2023). A Review on Benzimidazole Heterocyclic Compounds: Synthesis and Their Medicinal Activity Applications. SynOpen, 7(04), 652-673.

[53]. Ismaeel, G. L., Hussein, S. A., Daminova, G., Sulaiman, J. M. A., Hani, M. M., Kadhum, E. H., ... & Kianfar, E. (2024). Fabrication and investigating of a nano-structured electrochemical sensor to measure the amount of atrazine pollution poison in water and wastewater. Chemical Data Collections, 51, 101135.

[54]. Mahmoud, Z. H. (2018). Effect of Au doping on the magnetic properties of Fe3O4 NPs prepared via photolysis and co-precipitation methods. Diyala journal for pure sciences, 14(3).

[55]. Mahmoud, Z. H., AL-Bayati, R. A., & Khadom, A. A. (2021). Electrochemical photocatalytic degradation of Rhodamine B dye by Sm3+ doped Titanium dioxide (Sm-TiO2) in natural sunlight exposure. International Journal of Electrochemical Science, 16(12), 211241.

[56]. Mahmoud, Z. H., Abdalstar, O. D., & Sabah, N. (2020). Semiconductor metal oxide nanoparticles: a review for the potential of H2S gas sensor application. Earthline Journal of Chemical Sciences, 4(2), 199-208.

[57]. Mahmoud, Z., Emad Khalaf, O., & Alwan Farhan, M. (2019). Novel photosynthesis of CeO2 nanoparticles from its salt with structural and spectral study. Egyptian Journal of Chemistry, 62(1), 141-148.

[58]. Mahmoud, Z. H., AL-Bayati, R. A., & Khadom, A. A. (2022). Modified anatase phase of TiO2 by WO3 nanoparticles: Structural, morphology and spectral evaluations. Materials Today: Proceedings, 61, 799-804.

[59]. Saadh, M. J., Al-Salman, H. N. K., Hussein, H. H., Mahmoud, Z. H., Jasim, H. H., hassan Ward, Z., ... & Kianfar, E. (2024). Silver@ Copper-Polyaniline nanotubes: synthesis, characterization and biosensor analytical study. Results in Chemistry, 9, 101614.

[60]. Mohammadkhani, F., Mohammadkhani, A., Ajaj, Y., Almulla, A. A., Al Tameemi, A. R., & Mahmoud, Z. H. (2024). An experimental study on absorption and catalytic activity of molybdenum-schiff bases complex immobilized on Tl2O3–SiO2 nanoparticles. Case Studies in Chemical and Environmental Engineering, 9, 100684.

[61]. Kaduim, D., Mahmoud, Z., & Mousa, F. (2021). Green biosynthesis of iron oxide nanoparticles and testing their inhibitory efficacy against some pathogens. Asian Journal of Water, Environment and Pollution, 18(4), 119-123.

[62]. Al-Obaidi, N. S., Mahmoud, Z. H., Ali, A. A. F. A. S., & Ali, F. K. (2018). Evaluating The Electric Properties of Poly Aniline With Doping ZnO and?-Fe2O3 Nanoparticles. Pharmacophore, 9(5-2018), 61-67.

[63]. Hsu, C. Y., Jabbar, A. H., Shather, A. H., Alkhayyat, A. S., Alsalamy, A., Hamad, A. K., ... & Abed, Z. T. (2023). Utility of (MgO) 12 nanocage as a chemical sensor for recognition of amphetamine drug: a computational inspection. Chemical Physics Impact, 7, 100382.

[64]. Ibrahim, W. A., & Mahmoud, Z. H. (2018). Synthesis and characterization of new Fe-complex and its nanoparticle oxide using the novel photolysis method. International Journal of Pharmaceutical and Phytopharmacological Research, 8, 57-61.

[65]. Mahmoud, Z. H., & Abdalkareem, A. (2017). Removal of Pb ions from Water by Magnetic Iron Oxide Nanoparticles that Prepared via ECD. European Journal of Scientific Research, 145(4), 354-365.

[66]. Abd, A. N., & Mahmoud, Z. H. (2018). Synthesis of a-Fe2O3 Nano Powders by Novel UV Irradiation Method.

[67]. Farhan, M. A., Ali, W. B., Ibrahim, W. A., & Mahmoud, Z. H. (2024). Anti-cancer Schiff bases as photostabilizer for poly (vinyl chloride). Bulletin of the Chemical Society of Ethiopia, 38(1), 135-146.

[68]. Siswanto, W. A., Borodin, K., Mahmoud, Z. H., Surendar, A., Sajjadifar, S., Abdilova, G., & Chang, J. (2021). Role of aging temperature on thermomechanical fatigue lifetime of solder joints in electronic systems. Soldering & Surface Mount Technology, 33(4), 232-239.

[69]. Mahmoud, Z. H., Hashim, M., & Ali, F. K. (2019). Low temperature photosynthesis of Bi2O3 nano powder. Earthline Journal of Chemical Sciences, 2(2), 303-307.

[70]. Omran, N. A. J., Mahmoud, Z. H., Ahmed, N. K., & Ali, F. K. (2019). Low-temperature Synthesis of α-Fe 2 O 3/MWCNTs as Photocatalyst for Degradation of Organic Pollutants. Oriental Journal of Chemistry, 35(1).

[71]. Mahmoud, Z. H., Hassan, K. H., Sattar, O. D. A., & Ali, F. K. (2018). Low Temperature Novel Photosynthesis Method and Characterization of ZnO/CuO Nano composit. Journal of Biochemical Technology, 9(3-2018), 1-4.

[72]. Saadh, M. J., Jasim, S. A., Jameel, M. K., Kumar, A., Qassem, L. Y., Alhaidry, W. A. H., ... & Mahmoud, Z. H. (2024). Phosgene oxime detection by Ag-decorated and Ag-doped aluminum nitride nanotubes: Density functional theory studies. Solid State Communications, 380, 115431.

[73]. Mahmoud, Z. H., Hussein, S. A., Hassan, E. A., Abduvalieva, D., Mhaibes, R. M., Kadhum, A. A. H., ... & Faghih, S. (2024). Characterization and catalytic performance of rGO-enhanced MnFe2O4 nanocomposites in CO oxidation. Inorganic Chemistry Communications, 169, 113037.

[74]. Mahmoud, Z. H., AL-Salman, H. N. K., Hussein, S. A., Hameed, S. M., Nasr, Y. M., Khuder, S. A., ... & Sayadi, H. (2024). Photoresponse performance of Au (nanocluster and nanoparticle) TiO2: Photosynthesis, characterization and mechanism studies. Results in Chemistry, 10, 101731.

[75]. Li, Y., Fang, Y., Ning, W., Saraswat, S. K., Said, E. A., Mahmoud, Z. H., ... & Kadhum, E. H. (2024). The B3S monolayer as a two-dimensional material for seeing of HCHO molecules as environmental and water pollutants. Physica B: Condensed Matter, 676, 415656.

[76]. Mahmoud, Z. H., & Kianfar, E. (2024). Application of Nano Technology in the Self-Cleaning Finishing of Textiles: A Review. J Textile Eng & Fash Tech, 6(1), 01-13.

[77]. Jazaa, Y., Abdulkareem, R., Fiallos, L. M. F., Saraswat, S. K., Abdullaev, S., Castillo, R. M. T., ... & Rajhi, A. A. (2024). Aniline-Naphthylamine Copolymer Integrated with Aluminum Terephthalate-Based Metal Organic Framework for Efficient Hydrogen Evolution From Seawater. Journal of Materials Engineering and Performance, 1-8.

[78]. Sadeq, Z. E., Al-Obaidi, N. S., Al-Mahdawi, A. S., Abd, A. N., Mahmoud, Z. H., & Kamal, B. W. (2024). Preparation of nanocomposites for corrosion treatment. Bulletin of the Chemical Society of Ethiopia, 38(2), 501-509.

[79]. Mahmoud, Z. H., Ahmed, N. S., Shamkhi, W., & Dha'a, O. (2020). Nanoparticles: A review of preparation and characterization of nanoparticles with application. Earthline Journal of Chemical Sciences, 3(2), 141-149.

[80]. Mahmoud, Z. H., Hussein, U. A. R., Dhiaa, A. M., Al-Hussainy, A. F., Aljbory, N., Shuhata, M. H., ... & Thomas, S. (2025). Nano-Based Drug Delivery in Cancer: Tumor Tissue Characteristics and Targeting. Trends in Sciences, 22(2), 9078-9078.

[81]. Al-Jamal, A. N., Hussein, U. A. R., Aljbory, N., Mahmoud, Z. H., Mirani, A., Kianfar, E., & Maleknia, L. (2024). Electrospun ZnO and GSH co-loaded PU/CS nanofibrous films as potential antibacterial wound dressings. Nano LIFE.

[82]. Mahmoud, Z. H., AL-Salman, H. N. K., & Kianfar, E. (2024). Nanoindentation: introduction and applications of a non-destructive analysis. Nano TransMed, 100057.

[83]. Mahmoud, Z. H., AL-Salman, H. N. K., Abdulameer, M. K., Abass, R. R., Ismael, T. N., Alhameedi, D. Y., ... & Jumaa, S. S. (2024). Electrochemical investigation of dopamine and hydroquinone by (Pd@ Au-PANI) nanocomposite. Nanomedicine Journal, 11(4).

[84]. Sultan, I. K., & Mahmoud, Z. H. (2024). Polyaniline/Titanium phosphate as a biosensor detection of glucose performance. International Journal of Electrochemical Science, 100671.

ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14651233

[85]. Hsu, C. Y., Al-Yasiri, S. A. M., Shather, A. H., Jalil, A., Al-Athari, A. J. H., Mahmoud, Z. H., ... & Kadhim, M. M. (2024). The capability of pure and modified boron carbide nanosheet as a nanocarrier for dacarbazine anticancer drug delivery: DFT study. Pramana, 98(2), 40.

[86]. Jawad, A. A., Mahmoud, Z. H., Chechan, R. A., Abbas, A. K., Hussein, H. K., Mohammed, R., ... & Alkhafaji, S. A. (2024). Local chemical compounds: synthesis and characterization with antibiotic application.

[87]. Chowdhuri, A., Gupta, V., Sreenivas, K., Kumar, R., Mozumdar, S., & Patanjali, P. K. (2004). Response speed of SnO2-based H2S gas sensors with CuO nanoparticles. Applied Physics Letters, 84(7), 1180-1182.

[88]. Jammi, S., Sakthivel, S., Rout, L., Mukherjee, T., Mandal, S., Mitra, R., ... & Punniyamurthy, T. (2009). CuO nanoparticles catalyzed C− N, C− O, and C− S cross-coupling reactions: Scope and mechanism. The Journal of organic chemistry, 74(5), 1971-1976.

[89]. Zhang, D. W., Yi, T. H., & Chen, C. H. (2005). Cu nanoparticles derived from CuO electrodes in lithium cells. Nanotechnology, 16(10), 2338.

[90]. Yin, M., Wu, C. K., Lou, Y., Burda, C., Koberstein, J. T., Zhu, Y., & O'Brien, S. (2005). Copper oxide nanocrystals. Journal of the American Chemical Society, 127(26), 9506-9511.

[91]. Rafiq, S., Raza, Z. A., Aslam, M., & Bakhtiyar, M. J. (2022). Graphene nanosheets decorated with copper oxide nanoparticles for the photodegradation of methylene blue. Chemical Research in Chinese Universities, 38(6), 1518-1525.

[92]. Mushtaq, F., Nazeer, M. A., Mansha, A., Zahid, M., Bhatti, H. N., Raza, Z. A., ... & Irshad, R. (2022). Poly (Vinyl alcohol)(PVA)-Based treatment technologies in the remediation of dye-containing textile wastewater. In *Polymer Technology in Dye-containing Wastewater: Volume 2* (pp. 1-21). Singapore: Springer Nature Singapore.

[93]. Sharafi, A., & Seyedsadjadi, M. (2013). Surface-modified superparamagnetic nanoparticles Fe3O4 PEG for drug delivery. *Magn. Resonance Imaging (MRI)*, *4*(6).

[94]. J. Zhu, D. Li, H. Chen, X. Yang, L. Lu, X. Wang, 2004, “Highly dispersed CuO nanoparticles prepared by a novel quick-precipitation method”, Materials Letters, 58, 3324 – 3327.

[95]. Mahmoud, Z. H., AL-Bayati, R. A., & Khadom, A. A. (2022). Synthesis and supercapacitor performance of polyaniline-titanium dioxide-samarium oxide (PANI/TiO2-Sm2O3) nanocomposite. Chemical Papers, 76(3), 1401-1412.

[96]. Suryatna, A., Raya, I., Thangavelu, L., Alhachami, F. R., Kadhim, M. M., Altimari, U. S., ... & Kianfar, E. (2022). A Review of High-Energy Density Lithium-Air Battery Technology: Investigating the Effect of Oxides and Nanocatalysts. Journal of Chemistry, 2022(1), 2762647.

[97]. Mahmoud, Z. H., AL-Bayati, R. A., & Khadom, A. A. (2022). Electron transport in dye-sanitized solar cell with tin-doped titanium dioxide as photoanode materials. Journal of Materials Science: Materials in Electronics, 33(8), 5009-5023.

[98]. Mahmoud, Z. H., Hammoudi, O. G., Abd, A. N., Ahmed, Y. M., Altimari, U. S., Dawood, A. H., & Shaker, R. (2023). Functionalize cobalt ferrite and ferric oxide by nitrogen organic compound with high supercapacitor performance. Results in Chemistry, 5, 100936.

[99]. Mahmoud, Z. H., Al-Bayati, R. A., & Khadom, A. A. (2022). In situ polymerization of polyaniline/samarium oxide-anatase titanium dioxide (PANI/Sm2O3-TiO2) nanocomposite: structure, thermal and dielectric constant supercapacitor application study. Journal of Oleo Science, 71(2), 311-319.

[100]. Mustafa, M. A., Qasim, Q. A., Mahdi, A. B., Izzat, S. E., Alnassar, Y. S., Abood, E. S., ... & Al-Salman, H. N. K. (2022). Supercapacitor performance of Fe3O4 and Fe3O4@ SiO2-bis (aminopyridine)-Cu hybrid nanocomposite. International Journal of Electrochemical Science, 17(10), 221057.