P- ISSN 1991-8941 E-ISSN 2706-6703
2024,(18), (01): 197 – 202
Journal of University of Anbar for Pure Science (JUAPS) Open Access

Study the optical and Antibacterial properties of the Ag Nano-Particles by Exploding of Wire technique

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ARTICLE INFO

Received: 11 / 09 /2024
Accepted: 11 / 11 / 2024
Available online: 19 / 06 / 2024

DOI: 10.37652/juaps.2023.143290.1133

Keywords:
exploding wire; nanoparticles;, E.coli;, Staphylococcus aureus;, silver.

ABSTRACT

In this study, silver nanoparticles were synthesized and characterized for their physical and antibacterial properties using the explosive wire method. Silver wire with a diameter of 0.3 mm was detonated in an ion-depleted liquid, resulting in the formation of distinctive physical, chemical, and biological properties in the silver nanoparticles. The explosive wire method was employed to prepare silver nanoparticles, which were applied in the field of bacterial inhibition. The optical properties were investigated, revealing strong absorption peaks in the visible and UV regions. These peaks exhibited significant absorption at 240 nm, with the absorption peak positions depending on the size and shape of the particles. Fourier-transform infrared spectroscopy (FTIR) of the silver nanoparticles showed the presence of polar groups such as -COO- and OH-. The absorption spectrum was broad and intense at 3448 cm^{-1}. The effect of the nanoparticles against bacteria was studied. The results demonstrated a pronounced inhibitory effect on bacteria due to the nanoparticles' ability to easily adhere to the bacterial cell membrane and access the bacterial cell's nuclear content. Consequently, a very high inhibition rate was confirmed.

Introduction

Nanotechnology is one of the fastest-growing technologies globally. Recent advancements in the use of metal nanoparticles found significant developments, particularly in industrial, medical, and agricultural applications. Nanoparticles have been produced using various techniques, with one of the physical methods being the Electric Explosion of Wires (EEW) technique, which has been widely employed by plasma physicists to generate and confine plasma. The explosive wire method is a cost-effective way to produce large quantities of metallic nanoparticles and has gained considerable importance recently [1].

Silver nanoparticles (Ag NPs) have gathered significant interest due to their unique properties compared to their larger counterparts. They are known for their antimicrobial and anti-inflammatory properties. At the nanoscale, atoms exhibit enhanced properties primarily due to their increased surface area [2].

Ag NPs, in particular, have become one of the most utilized metal nanoparticles in various medical applications. They play a crucial role in applications such as cancer diagnosis and treatment, as well as in biological applications like bacterial and fungal inhibition. These nanoparticles have shown potential in the field of medical diagnostics and therapy, as well as in combating infections [3].

2. Methodology

2.1 Preparation of silver nanoparticles

This technique involves the preparation of nanoparticles by passing a high current over a short period of time through silver metal wires with small diameters of 0.3 mm. Since a sudden decrease in the wire diameter occurs at the bursting point, which effectively reduces the contact cross-sectional area. The wire turns into steam and when the steam condenses into a deionized liquid, nano-sized particles are obtained.

2.2 Explosive wiring technique

The Electric Explosion of Wires (EEW) method is a vapor-phase technique used to produce metallic

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nanoparticles by vaporizing a thin metal wire through the passage of high current [4]. In this technique, an extremely high current is passed through a thin metal wire for a very short period. This results in a high temperature, transforming the wire into a plasma state. The wire explosion phenomenon represents a direct method for producing various types of metallic nanoparticles with diameters less than 100 nanometers. In this method, thin metal wires are explosively detonated either in the air or a liquid medium to generate sufficient energy deposition for wire vaporization and ionization. Finally, the condensed vapor forms nanoparticles in the nanoscale range [5].

Explosive wires are used production of nanoscale metallic particles. The properties of the resulting nano powders depend on various explosion conditions, such as the arc discharge energy, electrical parameters of the wires, energy input rate, the type of metal wire used, wire diameter, length, and microstructural and substructural features of the metal wires [6]. As shown in Figure (1)

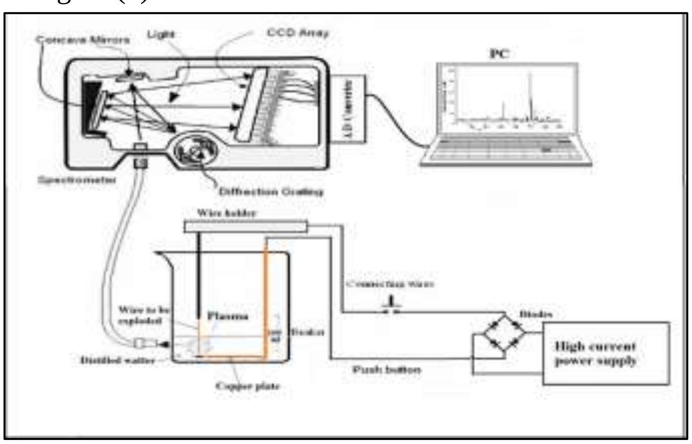

Figure1. The device used to detonate wires electrically.

3. Results and discussion

3.1. UV- visible spectroscopy

UV range is the primary method for determining the characteristics of nanoparticles by observing the resonance peak known as the surface plasmon resonance (SPR) peak. Figure (2) shows absorption as a function of wavelength. And that the samples exhibit spectral properties in the range of 350nm to 800nm.

The absorption spectrum of Ag NPs resulting from wire explosion, using a wavelength range spanning from 200 nm to 800 nm, shows strong absorption peaks at around 240 nm. This could be attributed to the interband transition of electrons from deep-level valence band (VB) electrons. As observed in the same figure, the peak absorption of Ag NPs is at 302 nm, indicating that the surface plasmon resonance of Ag NPs is size-dependent. This confirms that the peak at 302 nm is a criterion for small-sized nanoparticles with mono-dispersity in nature. When the particle size decreases, the wavelength (λ_{max}) of the resonance peak shifts towards shorter wavelengths, known as the blue shift [7].

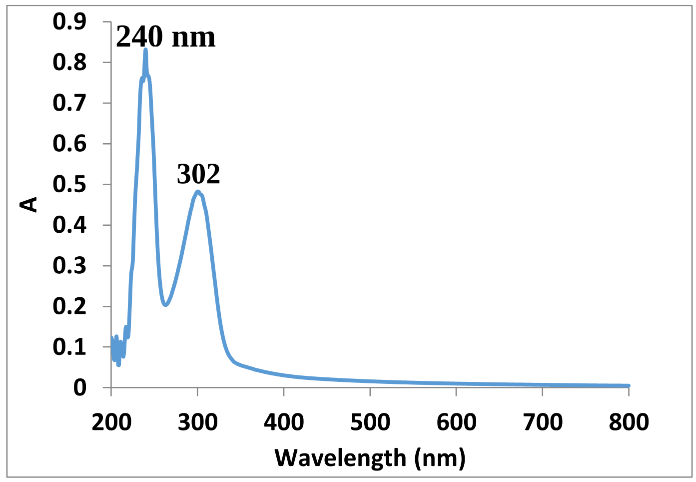

Figure 2. Absorption spectrum Ag NPs.

Using the tauc equation the band gap energy of Ag nanoparticles can be calculated indirectly from the absorption spectra. Tauc analysis involves obtaining optical absorption data of the sample, which covers a range of energies from the bottom to the top of the band gap. According to this equation, plotting $(\alpha h\upsilon)^2$ against (hv) and observing the linear portion of the curve allows to determine the band gap energy of the Ag NPs as illustrated in Figure (3). Band gaps for Ag NPs (eV 3.7 and 4.7) were found, and the higher band gap value can be attributed to the quantum confinement effect [8-9].

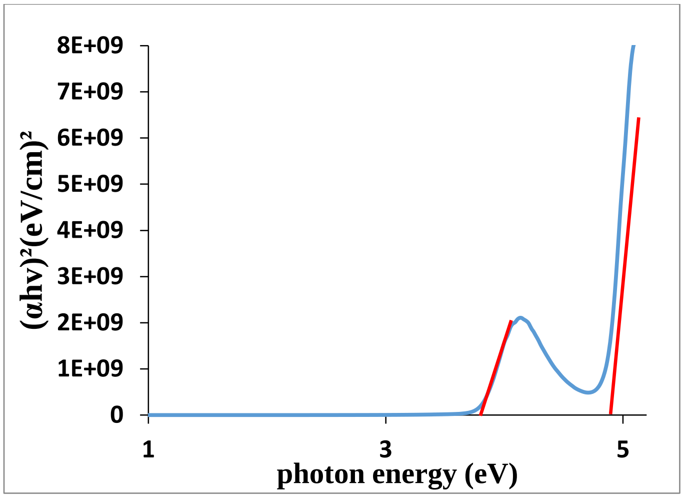

Figure 3. The band gap energy of silver nanoparticles.

3.1.1. Reflectance spectrum and refractive index

Figure (4) illustrates the reflectance spectrum and refractive index as a function of wavelength in the range of 250-800 nm for Ag NPs. The reflectance (R) and refractive index were calculated for the samples using equation(1) [10], [11].

$$R+T+A=1 \qquad \ldots\ldots\ldots\ldots 1$$

Where T: Transmittance A: Absorbance R: Reflectance

From Figure (4a), it is found that the sample exhibited high transmittance in the range of 40-25% and low reflectance of less than 15%. The refractive index value was calculated using the absorbance spectrum within the range of 250-800 nm. Figure (4b) illustrates the refractive index of Ag NPs as a function of wavelength. It can be observed that the refractive index decreases with increasing wavelength, which is similar to the behavior of reflectance. Additionally, in the wavelength range of less than 300 nm, there is an increase in the refractive index. This increase is a result of the decrease in particle size, leading to an overall increase in the refractive index. This is due to the increased transition value. However, in the range above 350 nm, the refractive index decreases due to the decrease in reflectance. The high refractive index value is considered good for optoelectronic devices.

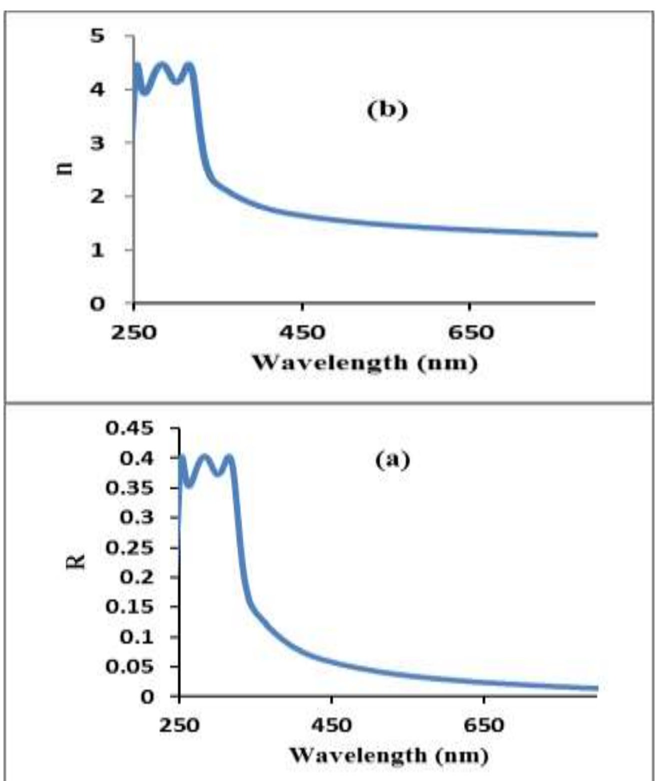

Figure ab-4. shows the spectra of reflectance and refractive index for Ag NPs.

3.2. Fourier- transform infrared spectrometer (FTIR)

FTIR was used to provide information about the molecular structure samples. The spectroscopic analysis classified into three regions: far-infrared FIR (50-1000 cm^{-1}), mid-infrared MIR (200- 4000 cm^{-1}), and near-infrared NIR (4000-12800 cm^{-1}) [12]. The most common region used is in the range of 200-4000 cm^{-1}. The diagnostic process in FTIR spectroscopy relies on the molecular bond's absorption at a specific frequency [13].

Figure (5) displays FTIR spectra for Ag NPs obtained from the wire explosion technique in the range of (400-4500 cm^{-1}). By observing the FTIR in Figure (5), polar groups (-COO- and OH-) indicating the presence of a water surface on Ag NPs can be seen. A high absorption peak is observed at 3448 cm^{-1}, associated with the stretching vibrations of the OH- group. Two absorption bands associated with symmetric and asymmetric stretching vibrations of -COO- groups are identified at 1636 cm^{-1} and 1384 cm^{-1}, respectively. Which correspond to the results obtained [14],[15].

The peak at 487.1 cm^{-1} corresponds to Ag-O, and the Ag-Ag metal bonds typically occur below 400 cm^{-1}. because FTIR uses the mid-infrared (400-4000 cm^{-1}) ,The peak belonging to the vibration of Ag-Ag metal bonds is not visible in this graphical representation [16],[17].

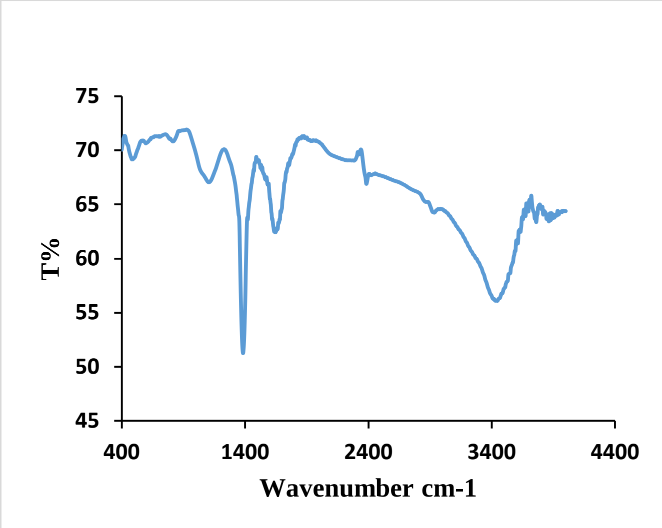

Figure 5. displays the infrared spectrum of Ag NPs**.**

3.3. Dynamic light scattering measurements DLS

Dynamic light scattering is considered one of the most important techniques for determining the size of prepared nanoparticles. It is also known as "light scattering analysis," and it is an easy technique that uses, to measure the size of nanoparticles in a solution [18].

Figure (6) illustrates the size distribution of silver nanoparticles (Ag NPs) prepared using the explosive wire method. In this method, a 0.3mm diameter silver wire was used in an ion-free liquid. The results showed the presence of nanoparticles ranging in size from 200 to 70 nm. The nanoparticles suspended in the liquid exhibit Brownian motion, which is caused by random collisions of the particles, leading to their dispersion throughout the medium [19].

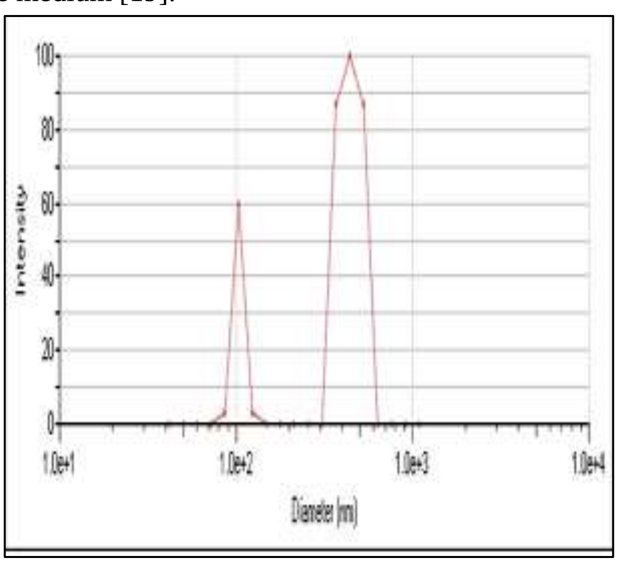

Figure 6. illustrates the shape of silver nanoparticles.

3.4. The effect of nanoparticles on bacteria.

Nanoparticles are now considered an alternative to antibiotics and have a high potential to address the issue of bacterial resistance to multiple drugs. The use of Ag NPs as against both Gram-negative and Gram-positive bacteria has been found effective due to their low cellular toxicity. The inhibitory effect is attributed to the size of its particles, allowing them easily adhere to the bacterial cell membrane and penetrate into the bacterial cell's nucleus, disrupting its structure and making it highly permeable, leading to ion leakage and cell contents leakage. This enzymatic disruption ultimately results in cell death [20].

After measuring the inhibition and bacterial growth area, the impact of silver nanoparticles prepared by the explosive wire method on Staphylococcus aureus and Escherichia coli was studied. The results showed a very high inhibition rate, as shown in Figure (7) for Staphylococcus aureus and a very high killing rate, as shown in Figure (8), illustrating the silver nanoparticles' killing effect on Escherichia coli. It was observed that the inhibitory zone was more pronounced around the positive sample, indicating a strong antibacterial ability against Staphylococcus aureus.

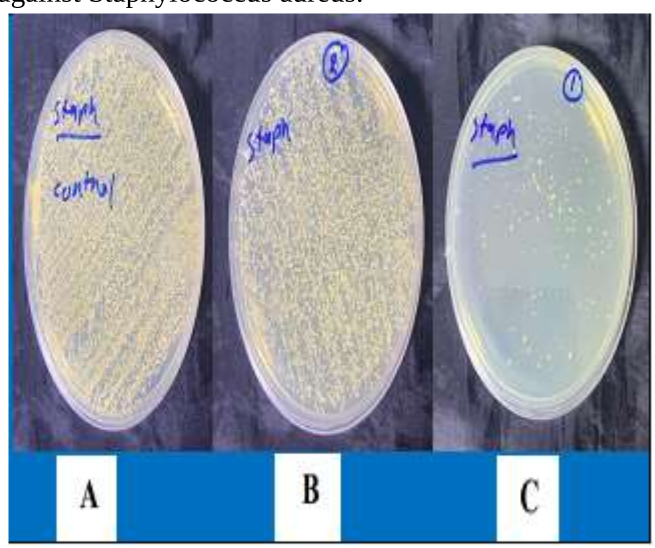

Figure7. illustrates the inhibition percentage of Ag NPs on Staphylococcus aureus bacteria.

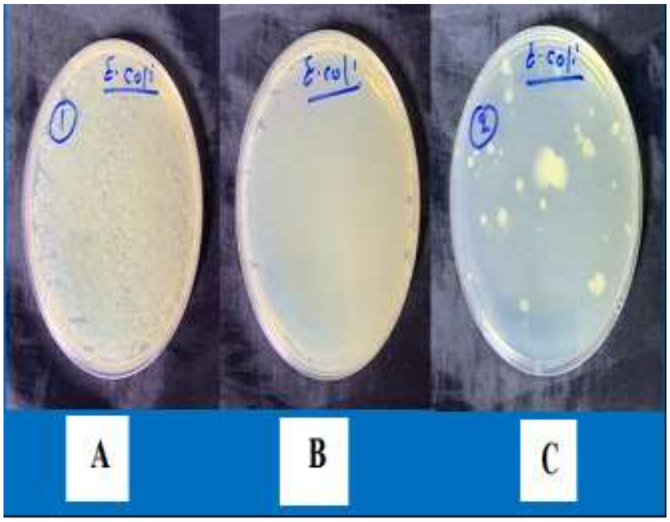

Figure 8. depicts the inhibition percentage of Ag NPs on E.coli bacteria.

4.Conclusion

Silver nanoparticles are considered one of the most attractive types of nanoparticles due to their reactivity at the nanoscale and their unique physical and chemical properties. The results have shown that nanoparticles can be prepared using the explosive wire technique, which is reflected in the absorption spectrum of silver nanoparticles. The absorption peaks of the Ag NPs spectrum show strong absorption at around 240 nm. Furthermore, a peak at 302 nm was observed, indicating that the surface plasmon resonance of Ag NPs is related to the size of the nanoparticles. In addition, FTIR spectra of Ag NPs obtained from the wire explosion technique in the range of 400 cm^{-1} to 4500 cm^{-1} revealed polar groups (-COO- and OH-), indicating the presence of water molecules on Ag NPs' surface. A high absorption band was observed at 3448 cm^{-1}. DLS results indicated the presence of nanoparticles with sizes from (70 - 200 nm). The suspended nanoparticles in the liquid exhibited Brownian motion. After studying the effect of silver nanoparticles prepared by the explosive wire method on E.coli and Staphylococcus aureus bacteria. the results showed a very high inhibition rate.

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دراسة الخصائص البصرية والمضادة للبكتيريا لجزيئات الفضة النانوية بتقنية تفجير الأسلاك

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الخلاصة:

في هذه الدراسة تم توليف وتوصيف الخصائص الفيزيائية والمضادة للبكتيريا للجسيمات النانوية الفضية المحضرة بطريقة الاسلاك المتفجرة حيث تم استخدام سلك من الفضة قطره 0.3mm وتفجيره داخل سائل منزوع الأيونات وأظهرت الجسيمات النانوية من الفضة خصائص فيزيائية وكيميائية وبيولوجية مميزة. حيث تم استخدام طريقة الاسلاك المتفجرة لتحضير جزيئات الفضة النانوية وتطبيق هذه الجسيمات في مجالات تثبيط البكتيريا. تم دراسة الخصائص البصرية حيث اثبت فحص UV- Visible وجود قمم امتصاص Ag NPs والتي تظهر امتصاصًا قويًا عند (240 nm) وأن مواضع ذروة الامتصاص تعتمد على حجم الجسيمات وشكلها. واظهر طيف FTIR لجسيمات الفضة النانوية وجود مجموعات قطبية (−COO و −OH). حيث أظهر نطاق امتصاص مكثف وواسع عند 3448 وتم دراسة تأثير الجسيمات النانوية ضد البكتيريا موجبة الغرام وسالبة الغرام وأثبتت النتائج التأثير المثبط للبكتيريا بسبب سهولة الالتصاق بغشاء الخلية البكتيرية والوصول إلى المحتوى النووي للخلية البكتيرية وبالتالي اثبتت نسبة تثبيط عالية جدا.

الكلمات المفتاحية: سلك متفجر الجسيمات النانوية، بكتريا قولونية، المكورات العنقودية ، فضة.