

# Facile Preparation of Silver Halide Nanoparticles for Biological Application and Waste Water Treatment

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# Abstract

Highly efficient silver halide nanoparticles (AgX, X = Cl, Br NP's) were successfully synthesized by facile and template-free direct-precipitation method using potassium chloride, potassium bromide and silver nitrate as reactive sources. The as-prepared AgX NP's were characterized by FTIR, thermogravimetric analysis, XRD, EDX and HRTEM. The antimicrobial susceptibilities against two Gram-positive bacteria (*Bacillus cereus, Staphylococcus aureus*) and four Gram-negative bacteria (*Salmonella typhi, Escherichia coli, P. aeruginosa* and *Klebsiella pneumoniae*) in addition to five fungi (*Aspergillus flavus, A. carbonarus, Penicillium verrucosum, Fusarium verticelloides* and *A. niger*) were tested by the disk diffusion technique. The antibacterial and antifungal results suggest that the prepared AgX NP's show high activity against the tested organisms compared to tetracycline and Nystatin taken as standard drugs. As an application, the use of the prepared AgX NP's as photo catalyst for the decontamination of malathion as VX chemical warfare agent (CWA) stimulant from water sample was extensively studied.

## **Keywords**

AgX Nanomaterials, Antibacterial and Anti Fungal Activity, Photo Catalytic Decontamination of Malathion

# **1. Introduction**

Nano crystalline silver halide (AgX NP's), as classes of highly photosensitive semiconductor materials, have received increasing research attention owing to their unique chemical, physical and biological properties [1] [2] [3] [4]. They have excellent visible-light-driven photo catalytic performance for applications in organic pollutant degradation, biomedical and bioanalytical fields [5] [6] [7]

[8] [9]. In addition, AgX NPs have been widely used in several areas of water treatment [10] [11], medicine [4], photocatalysis [12] [13], biotechnology [14] [15] and cancer therapy [16]. Silver halides can be used as metallic silver precursors [17]. When they absorb photons an electron and a hole are produced. This causes an electron transfer and, subsequently, the Ag<sup>+</sup> transforms to Ag<sup>0</sup> converting the surface to tiny clusters of silver atoms which can catalyze the reduction of AgX NP's to Ag nano particle in the presence of mild reducing reagents, known as self-catalytic reduction [17]. This leads to the formation of hybrid AgX/Ag nanoparticles providing a class of promising visible-light-driven photocatalysts for environmental remediation [18]. In this article, and in continuation to our previous works [19]-[25], silver halide nanoparticles (AgX, X = Cl, Br NP's) were successfully synthesized by facile and template-free direct-precipitation method in dark atmosphere conditions and characterized by different techniques. The antimicrobial susceptibilities against two Gram-positive bacteria, four Gram-negative bacteria and five fungi were tested by the disk diffusion technique. As an application, the use of the prepared AgX NP's as photo catalyst for the decontamination of malathion (an VX chemical warfare agent, CWA, stimulant) from water sample was extensively studied.

# 2. Experimental

# 2.1. Materials and Reagents

All chemicals used in the present study were of pure grade (Aldrich or Merck) and were used without further purification. Silver nitrate (>99.95%, Sigma), potassium chloride and potassium bromide; KCl, KBr, >99.5%, Merik Chemical A. R. and Polyvinylpyrrolidone (PVP, average MW = 40,000, 30 mg/mL, Sigma) were used as received, without additional purification. Bi-distilled water was used whenever water is used.

## Preparation of silver halide (AgX)

Silver chloride Nanoparticulate (AgCl NP) was prepared by titrating 500 mL aqueous solution of KCl (0.02 M) drop wisely to 100 mL aqueous solution of AgNO<sub>3</sub> (0.01 M) mixed with a solution of polyvinylpyrrolidone (PVP) at room temperature. The solution mixture was stirred continuously for about three hours keeping the reaction vessel in a dark place to prevent the formation of metallic Ag<sup>0</sup>. Precipitation was achieved immediately and the formed precipitate was isolated and washed three times with bidistilled water then finally with acetone to expel water from the surface. The solid product was dried at 60°C for  $\approx$  6 hours then grinned in an agate mortar into a fine powder and stored in an amber vial since AgCl is known to be photosensitive. Synthesis of silver bromide Nanoparticulate (AgBr NP) was performed via the same procedure using KBr instead of KCl as a precursor.

# 2.2. Instruments and Characterization Methods

1) FTIR spectra: were recorded on a Nicolet iSio FT-IR spectrophotometer in

the 4000 - 400 cm<sup>-1</sup> region using KBr disk technique (Chemistry department, Faculty of science, Benha University, Egypt).

2) Thermal analysis: Thermogravimetric analysis (TGA-DTG) were carried out using Shimadzu TGA-50H thermal analyzer within the temperature range  $25^{\circ}$ C -  $800^{\circ}$ C (Central Lab, Faculty of Science, Ain Shams University, Cairo, Egypt). All measurements were done under nitrogen atmosphere at heating rate of  $10^{\circ}$ C/min.

**3)** *Electronic spectra*: Electronic spectra of nanoparticles were measured in the solid state (Nujol Mull technique) using Jasco V-530 (UV-Vis) double beam spectrophotometer (Japan) with scanning speed 400 nm/min and band width 2.0 nm using 10 mm matched quartz cell at room temperature in the range 800 - 200 nm at Faculty of Science, Benha University, Benha, Egypt.

4) *X-ray diffraction*: X-ray diffraction analysis (XRD) was carried out using SIEMENS D5000 instrument. The patterns were run with Cu-filtered CuK<sub>a</sub> radiation of wavelength 1.79 A° energized at 45 kv and 10 mA. The sample was measured at room temperature in the range of 20 from 20° - 80°.

**5)** *High resolution transmission electron microscopy*. The morphology and particle shape of the as-prepared samples were studied by high resolution transmission electron microscopy (HRTEM) using JEOL TEM 2100 high resolution electron microscope at 100 kv by dispersed sample in ethanol on a copper grid.

**6)** *Energy dispersive X-ray (EDX)*: The energy dispersive X-ray spectroscopy (EDX) was measured with a Horiba EMAX X-act energy dispersive spectroscopy that was attached to the Hitachi S-4800 system.

# 2.3. Antimicrobial Screening

The antimicrobial susceptibilities against two Gram-positive bacteria (*Bacillus cereus, Staphylococcus aureus*) and four Gram-negative bacteria (*Salmonella typhi, Escherichia coli, P. aeruginosa* and *Klebsiella pneumoniae*) in addition to five fungi (*Aspergillus flavus, A. carbonarus, Penicillium verrucosum, Fusarium verticelloides*, and *A. niger*) (*Salmonella typhi, Escherichia coli, P. aeruginosa* and *Klebsiella pneumoniae*) were tested by the disk diffusion technique developed by Bauer *et al.* [26] and described in our previous work [27]. The method is based on the determination of an inhibited zone proportional to the bacterial susceptibility to the antimicrobial present in the disk. Three replicas were made for each treatment to minimize error.

## 2.4. Photocatalytic Degradation of Malathion

For a typical photocatalytic experiment, 50 mg of (AgX NP) was added to 100 mL of 0.06 mL/l malathion solution (Malathion purity >95% from Nasr Company for Intermediate chemicals, Egypt) and was kept in dark for 6 hours to allow the system to reach an adsorption desorption equilibrium. Adsorption kinetics experiments were operated in a series of 250 mL beakers containing AgX NP's and 100 mL of malathion solutions with continuous stirring at 25°C under

the UV illumination using a 250 W xenon arc lamp (Thoshiba, SHLS-002) ( $\lambda$  = 365 nm). After recovering the catalyst by centrifugation, the process was followed up by scanning the UV-Vis spectra at different time intervals within the wavelength range 220 - 350 nm and the band of maximum absorbance at 270 nm ( $\lambda_{max}$  for Malathion) was taken to follow up the degradation process.

# 3. Results and Discussion

## 3.1. Characterization of the AgX Nanoparticles (AgX NP's)

The as-prepared AgX NP's were firstly subjected to extensive study to confirm their chemical structure. Different techniques were performed for this purpose:

## **3.1.1. Thermal Analysis**

Inspection of the TG-DTA curves shows that both AgCl and AgBr NP's undergo thermal degradation through two endothermic steps. The first takes place within the range 60.0°C - 70.0°C (weak endothermic peak accompanied by  $\approx$  5.20% weight loss) corresponding to the removal of physically adsorbed water molecules from the outer surface of the nano particles. The second step occurs within the range 320°C - 325°C (strong endothermic one accompanied by  $\approx$  28.00% weight loss) represents the decomposition of the unhydrous AgX NP's leading to the formation of Ag<sub>2</sub>O as final products. The thermograms of the two samples show thermal stability with no further thermal events up to 800°C indicating that the stable residues can be ascribed as silver oxide (Ag<sub>2</sub>O) crystalline particles.

#### 3.1.2. IR Spectra

The IR spectra (representative example is shown in **Figure 1**) show the expected characteristic bands in the shortwave region around 690 - 650 cm<sup>-1</sup> due to the stretching vibration associated with bonds containing a heavy element [19] [21]



Figure 1. IR spectrum of AgCl NP.

(which is silver here). The bands related to each peak in these spectra are summarized as: 1) Symmetric stretching vibration of the physically adsorbed water molecules at about 3450 cm<sup>-1</sup>, 2) Symmetric and asymmetric stretching vibration of Ag-Cl and Ag-Br bonds at 690 - 650 cm<sup>-1</sup> and 3) Bending vibration of C-N bonds at 586 cm<sup>-1</sup>. The latter band may be due to the vibration of coating proteins.

## 3.1.3. High Resolution Transmission Electron Microscopy (HRTEM)

The TEM images of the prepared nano particles were scanned with different magnification powers (500 - 5000). For AgCl NPs, the TEM image clearly shows that they are cube-shaped single crystallites with the size in the range of 20 nm, which reflects the intrinsic cubic symmetry of AgCl. The TEM image of the AgBr NPs (**Figure 2**) indicates that they are spherical in shape and uniform in size, with an average particle size of 35 nm. These images also show that the NPs are well dispersed and not aggregated.



Figure 2. HRTEM images of AgBr NP with different magnification powers.

#### 3.1.4. Energy Dispersive X-Ray Spectroscopy (EDX)

To validate the generation of AgCl and AgBr nanoparticles, they were investigated by energy dispersive X-ray analysis (EDX). For AgCl NP, (*c.f.* Figure 3(a)), EDX analysis displayed high intensity two absorption peaks at 3.04 and 2.54 kV, indicating the presence of Ag and Cl, respectively. A semiquantitative analysis (*c. f.* Table 1) showed that silver constitutes 45.78% while chlorine constitutes 50.29% and the atomic ratio Ag:Cl elements is approximately 1:1. The data are in agreement with the theoretical stoichiometric atomic ratio between Ag and Cl species in AgCl. The above findings confirmed that Ag and Cl are the major elements found in the composition of AgCl nanoparticles. Oxygen has 3.26%, probably due to the release of coating proteins.



Figure 3. EDX spectrun of (a) AgCl and (b) AgBr nanorticle.

Table 1. Elemental analusis of AgCl nanoparticle.

Element	Line	Mass%	Atom%
0	K	$0.77\pm0.09$	3.26 ± 0.39
Cl	К	$26.58\pm0.41$	$50.95\pm0.79$
Ag	L	$72.66 \pm 0.96$	$45.78\pm0.61$
Total		100.00	100.00
Spc_	001	Fitting rat	io 0.1142

EDX analysis of the AgBr nanoparticle is shown in Figure 3(b) and Table 2. The spectrum displayed a medium intensity peak at 1.50 kV indicating the presence of bromine constitutes and a high intensity peak at 3.01 kV, due to silver. The percentages of bromine and chlorine in the sample amount to 42.60% and 44.39%, respectively proofing the presence of silver bromide nanoparticle. Oxygen and carbon have the percentage of 5.71% and 4.08% respectively, probably due to the release of coating.

Element	Line	Mass%	Atom%
С	К	$4.08\pm0.10$	19.69 ± 0.48
0	К	$5.71 \pm 0.20$	$20.71\pm0.72$
К	К	$3.23\pm0.17$	$4.80 \pm 0.25$
Br	L	$42.60 \pm 0.55$	$30.93\pm0.40$
Ag	L	$44.39\pm0.68$	$23.87\pm0.37$
Total		100.00	100.00
Spc_	001	Fitting rat	tio 0.0762

Table 2.	Elemental	analusis	of AgBr	nanoparticle.
			· 0	

#### 3.1.5. X Ray Diffraction Spectra (XRD)

The XRD spectral data, cited in **Table 3**, of the AgCl NP show that the distinct diffraction peaks at a  $2\theta$  of 28.412°, 32.832°, 46.809°, 55.367°, 58.018° and 67.92° could be assigned to the (111), (200), (220), (311), (222) and (220) planes, respectively, for the typical cubic phase of AgCl crystal (JCPDS file 31-1238). This suggests the existence of AgCl species in the synthesized nano structures. The lattice parameters indicate the presence of Chlorargyrite (cubic with  $a = b = c = 5.7713 \text{ A}^\circ$ ) and Periclase (cubic with  $a = b = c = 3.8908 \text{ A}^\circ$ ) as phases. The most intense peak (intensity 100%) is from the (200) plane which corresponds to angles of  $2\theta = 32.832^\circ$ . The average crystalline size calculated from Scherrer equation were found to be 25 nm.

The XRD pattern of the nanosized AgBr (*c.f.* Figure 4 and Table 4) shows diffraction peaks located at  $2\theta = 26.456^{\circ}$ ,  $31.182^{\circ}$ ,  $44.569^{\circ}$ ,  $52.754^{\circ}$  and  $55.282^{\circ}$  corresponding to (111), (200), (220), (311) and (222) planes for typical cubic phase (AgBr). The lattice parameters indicate the presence of Halite (cubic with  $a = b = c = 5.74456 \text{ A}^{\circ}$ ) and AgBr (cubic with  $a = b = c = 5.74508 \text{ A}^{\circ}$ ) as phases. The most intense peaks (intensity 100%) are from the (200) and (220) planes which corresponds to angles of  $2\theta = 31.182^{\circ}$  and  $44.569^{\circ}$ . The average crystalline size calculated from Scherrer equation was found to be 35 nm.

No	2 <i>θ</i> , °	Phase Name	Chemical Formula	Card No
1	28.412(5)	Chlorargyrite: 1 1 1	Ag Cl	9008597
2	32.832	Chlorargyrite: 2 0 0	Ag Cl	9008597
3	46.809	Chlorargyrite: 2 2 0, Periclas	Ag Cl, MgO	9008597, 9013210
4	55.367	Chlorargyrite: 3 1 1	Ag Cl	9008597
5	58.018	Chlorargyrite: 2 2 2	Ag Cl	9008597
6	67.92	Periclase: 2 2 0	MgO	9013210
7	75.03	Unknown		
8	77.14	Unknown		

Table 3. The XRD spectral data of AgCl NP.

Lattice parameters									
Phase name	a, <sub>Å</sub>	b, <sub>Å</sub>	с, <sub>Å</sub>	<i>a</i> , °	<i>β</i> , °	γ, °			
Chlorargyrite	5.47713	5.47713	5.47713	90.0	90.0	90.0			
Ag Br	3.89078	3.89078	3.89078	90.0	90.0	90.0s			

# Table 4. The XRD spectral data of AgBr NP.

No.	2 <i>θ</i> , °	Phase	e Name	Chemical Formula	C	Card No				
1	26.056	Halit	e: 1 1 1,	Cl Na,	9	006382,				
1	26.956	Ag B	r: 1 1 1	Ag Br	1	509151				
2	21 1010	Halit	e:2 0 0,	Cl Na,	9	006382,				
Z	51.1818	Ag B	r: 2 0 0	Ag Br	1	509151				
2	44 5 602	Halit	e:2 2 0,	Cl Na,	9	006382,				
3	44.5695	Ag B	r: 2 2 0	Ag Br	1	509151				
4	E2 7E4	Halit	e:3 1 1,	Cl Na,	9	9006382,				
4	4 52./54		r: 3 1 1	Ag Br	1	509151				
r	EE 201E	Halit	e:2 2 2,	Cl Na,	9	006382,				
5	55.2815	Ag B	Ag Br: 2 2 2		1	509151				
6	64.35	Unk	nown							
7	64.733	Unk	nown							
8	71.327	Unk	nown							
9	73.4869	Unk	nown							
	Lattice parameters									
Phase name	a, <sub>Å</sub>	b, <sub>Å</sub>	C, <sub>Å</sub>	<i>a</i> , °	β, °	γ, °				
Halite	5.74456	5.74456	5.74456	90.0	90.0	90.0				
Ag Br	5.74508	5.74508	5.74508	90.0	90.0	90.0				



Figure 4. XRD of AgBr nanoparticle.

#### **3.1.6. Optical Analysis**

A fundamental property of nanosized particulates is the band gap energy. The UV-Visible spectra allow direct determination of band gap using the relation between the absorption coefficient (*a*) and the incident photon energy (*hv*) represented by Tauc equation [28]:  $(\alpha hv) = A(hv - Eg)^n$ . Where, A is a constant,  $E_g$  is the band gap of the material and the exponent (n) depends on the type of transition, n is either 2 for an indirect transition or  $\frac{1}{2}$  for a direct transition. Here the best curve is found when n = 2 indicating indirect transition. The value of optical band gap is calculated by plotting the relation between  $(\alpha hv)^2$  vs hv and extrapolating the straight line portion to the hv axis. The UV-Visible spectra and Tauc plots of AgCl and AgBr nano particles in the solid state (Nujol mull technique) are shown in Figure 5 and Figure 6. The extrapolation of linear portion to the hv axis gives values of energy gap as 3.5 ev and 3.8 ev for AgCl and AgBr NP's, respectively.



Figure 5. Electronic absorption spectrum and Tauc plot of AgCl nano particle in nujol mull.



Figure 6. Electronic absorption spectrum and Tauc plot of AgBr nano particle in nujol mull.

# 3.2. Antimicrobial Screening

The antimicrobial susceptibilities against two Gram-positive bacteria and four Gram-negative bacteria in addition to five fungi were tested by the disk diffusion technique. Standard drug; tetracycline (500  $\mu$ g·ml<sup>-1</sup>) and dimethyforma-mide (DMF) were screened separately for their antibacterial activity as positive and negative controls, respectively, while Nystatin (1000 Unit·ml<sup>-1</sup>) and DMF were screened separately for their antifungal activity as positive and negative controls, respectively The antibacterial and antifungal results (*c.f.* **Table 5** and **Table 6**) suggest that the prepared AgXNP's show high activity against the tested organisms compared to tetracycline and Nystatin taken as standard drugs.

	Gram-negative bacteria							Gram-positive bacteria				
Tested species -	E. coli		P. aeruginosa		K. Pneumoniae		S. typhi		S. aureus		B. cereus	
	Inh. Zone	% Ac.Ind	Inh. Zone	% Ac.Ind	Inh. Zone	% Ac.Ind	Inh. Zone	% Ac.Ind	Inh. Zone	% Ac.Ind	Inh. Zone	% Ac.Ind
-ve control*	0	0	0	0	0	0	0	0	0	0	0	0
+ve control**	28.2	100	27.2	100	32.3	100	29.8	100	28.5	100	27.0	100
AgCl	25.8	91.49	25.7	94.49	30.2	93.86	30.2	101.34	26.9	94.39	28.1	104.07
AgBr	25.2	89.36	23.5	86.4	28.2	87.31	28.5	95.64	25.9	90.88	26.8	99.26

Table 5. Antibacterial activity (inhibition zone diameter (mm)) of tetracycline (500 µg·mL<sup>-1</sup>) and the as prepared AgXNP's.

\*Dimethylformamide (DMF); \*\*Tetracycline (500 µg·mL<sup>-1</sup>).

	Fungai										
Tested species	A. flavus		A. carbonarius		A. niger		F. verticillioides		P. verrucosum		
	Inh. Zone	% Ac.Ind	Inh. Zone	% Ac.Ind	Inh. Zone	% Ac.Ind	Inh. Zone	% Ac.Ind	Inh. Zone	% Ac.Ind	
-ve control*	0	0	0	0	0	0	0	0	0	0	
+ve control**	14.5	100	16.5	100	15	100	14.5	100	16.5	100	
AgCl	14.0	96.55	16.1	97.58	15.8	105.33	15.1	104.14	15.7	95.15	
AgBr	13.7	94.48	15.3	92.73	13.5	90.0	15.0	103.45	14.9	90.30	

Table 6. Antifungal activity (inhibition zone diameter (mm)) of Nystatin (1000 Unit-ml<sup>-1</sup>) and the as prepared AgXNP's.

\*DMF; \*\*Nystatin (1000 Unit·ml<sup>-1</sup>).

The most acceptable mechanism for the antimicrobial effect of the nano materials is the in-situ production of reactive oxygen species (ROS) which occurs by the metal surface reducing oxygen molecules [29]. The species produced in these reactions are the hydroxyl radical ( $\cdot$ OH), superoxide ( $O_2^-$ ), singlet oxygen ( $O_2$ ) and hydrogen peroxide ( $H_2O_2$ ). If the amount of ROS produced within the cell by metal nanoparticles increases too much the cell will not be able to survive the damage. This leads to the reduction of the activity of periplasmic enzymes which are needed for the health of the bacteria [29]. Silver nanoparticles have been shown to react with water to produce hydroxyl radicals and react with oxygen to produce superoxide and singlet oxygen [30].

## **3.3. Analytical Application**

Among the organophosphorus insecticides, malathion is the most widely used (32% - 44% of total organophosphorus insecticide) [31]. Malathion [S-(1,2-dicarbethoxyethyl)-O,O-dimethyldithiophosphate], is a non-systemic, wide-spectrum organo-phosphorus pesticide used in public health, residential, and agricultural settings. It is classified as a toxicity class III according to Environment Protection Agency (EPA) [32] and can be degraded chemically and microbiologically in water within a few weeks, but it can remain in the environment for months [33].

The photodegradation of Malathion as VX chemical warfare agent (CWA) stimulant and as widely used insecticide was studied without using catalyst and with using AgCl and AgBr NP's as catalysts. The results are represented, graphically in Figure 7 and Figure 8. Inspection of the absorption spectra and the calculated % degradation values shows that, after 240 min Malathion degraded maximally up to 48.5% under the effect of UV radiation only, while the percent degradation efficiencies reach 99.2% and 82.4% on using AgCl and AgBr nanoparticles, respectively as catalyst within only 120 min. This reflects the high efficiency of these materials for the removal of such toxic organic insecticide pollutant.



**Figure 7.** Effect of time on the degradation of malathion using AgCl NP as catalyst under UV irradiation.



**Figure 8.** Effect of time on the % degradation of malathion under the effect of: 1) UV radiation only, 2) AgCl NP as catalyst and 3) AgBr NP as catalyst.

Studies on the effect of pH on the % removal of malathion were studied keeping the mass of catalysts constant (0.1 g) and measuring the absorbance at 265 nm after 150 min constant stirring where it was found that (*c.f.* Figure 9) best removal takes place at, more or less, neutral solution (pH = 6.5 - 8.0).

## 3.3. Mechanism of Photocatalytic Activity of Ag/AgX

The photocatalytic mechanism of Ag/AgX nanocomposites is displayed in **Figure 10**, [4]. When photons are absorbed, AgX produces an electron and a hole. This causes an electron transfer and, subsequently  $Ag^+$  transforms into  $Ag^0$  so forming Ag/AgX NP acting as photocatalyst. The Ag metal as a conductor grown on the surface of AgX can easily generate electron-hole pairs, then those electrons in the valance band can absorb photons with energy equal to or higher

than the band gap energy. The main process that can generate reactive oxygen species (ROS) is the photo-generated charge-mediate redox reactions, which include the oxidation of  $H_2O$  to form OH<sup>+</sup> radicals, and the reduction of  $O_2$  to form (ROS) (e.g., singlet oxygen, hydroxyl radical, superoxide, hydroperoxyl radical, and hydrogen peroxide) [34] [35].



**Figure 9.** Effect of pH on the % degradation of malathion under the effect of: 1) UV radiation only, 2) AgCl NP as catalyst and 3) AgBr NP as catalyst.



**Figure 10.** The photocatalytic mechanism of pesticides on the surface of nanocatalyst. (plagiarized from Ref. 4; Zhang *et al.*, 2022).

# 4. Conclusion

Highly efficient silver halide nanoparticles (AgX, X = Cl, Br NP's) were successfully synthesized by facile and fast precipitation method. The as-prepared AgX NP's were characterized by FTIR, thermogravimetric analysis, XRD, EDX and HRTEM. The antimicrobial susceptibilities against two Gram-positive bacteria, four Gram-negative bacteria and five fungi were tested by the disk diffu-

sion technique. The antibacterial and antifungal results suggest that the prepared AgX NP's have high activity against the tested organisms compared to tetracycline and Nystatin taken as standard drugs. As an application, the use of the prepared AgX NP's as photo catalyst for the decontamination of malathion as VX chemical warfare agent (CWA) stimulant from water sample was extensively studied.

# **Conflicts of Interest**

The authors declare no conflicts of interest regarding the publication of this paper.

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