Improper management of discharged waste material such as toxic organic dyes from industries causes severe health and economic problems because contaminated water with organic dyes is harmful to human being and aquatic ecosystems. The photocatalyst is a preferable wastewater treatment method because it is environmentally benign, cost-wise, and more efficient in degrading dyes. Most metal oxide semiconductors are photocatalytic materials, but nowadays, Ag$_3$PO$_4$ nanoparticles have attracted enormous attention due to their low bandgap and high absorption of visible light. However, Ag$_3$PO$_4$ nanoparticles have low performance due to photocorrosion, high recombination rate, and instability in the solution. Thus, in this review article, the mechanism to enhance the photocatalytic activities of Ag$_3$PO$_4$ nanoparticles was discussed, and the future perspective of the silver phosphate was also stated.

1. Introduction

Global widespread industrialization has brought a change in human life by giving vast opportunities to get employment. On the other hand, poor management of industrial wastes such as heavy metals, dyes, pharmaceutical waste, and agricultural wastes caused severe environmental pollution because most of these discharged compounds are stable so that they can persist for a long time [1–3]. Amazingly, the final destination of all industrial wastes including solid form, liquid, or gas form ended in the water body. As a result, the degree of environmental pollution by contaminated water is enormous. So, water pollution has tremendous negative consequences on the economy and health of human beings. Vanishing aquatic lives and deteriorating health of human beings are mainly the results of water pollution [4, 5]. Wastewater treatment is crucial to get a healthy environment.

There are two types of wastewater treatment methods such as traditional and advanced wastewater treatment techniques. Conventional wastewater treatment methods are the following: coagulation, filtration, disinfection, sedimentation, de-chlorination, adsorption onto activated carbon, screening, chemical precipitation [4–6], screening, and chemical precipitation. However, advanced techniques such as membrane filtration, reverse osmosis, ion exchange, electro-dialysis, adsorption, and advanced oxidation process have been used widely for wastewater treatment [7]. The advanced oxidation process (AOPs) is one of the recent methods for wastewater treatment due to degrading nonbiodegradable, chemically stable, persistent pollutants and its low operating cost, no chemical agent needed, and minimal sludge formation. Furthermore, the AOPs generated reactive oxygen species (ROS) that oxidize a broad range of organic pollutants inside wastewater [8].

Three common types of AOPs are photocatalyst, photolysis, and photo-Fenton which are light irradiated based [9]. Among those, photocatalysts gained tremendous attention because of the following reasons: (i) a small number of catalysts able to degrade a large number of dyes; (ii) no need for external force, environmentally benign; and (iii) cost-effective technology, and the organic pollutants directly converted nonoffensive by-products such as CO$_2$ and H$_2$O.
Metal oxide semiconductors ZnO [3] and TiO2 are widely used photocatalytic materials owing to their low cost, strong redox capacity, and good thermal and chemical stability [12, 13]. However, they operate only under UV light due to their wide bandgap (3-3.2 eV). The UV light reaches the earth’s surface only 4-5% of the total solar spectrum, but the amount of visible light that arrives at the earth’s surface is 45%. Doping of ZnO and TiO2 reduces the bandgap of ZnO and TiO2. As a result, they can operate in the visible range. However, doping these metal oxides introduces a new energy level in the bandgap, which acts as the recombination center of photogenerated e−-h+ pairs. Such recombination of electrons-holes is the main factor to reduce the photocatalytic efficiency of TiO2 and ZnO [14–16]. To harvest a large amount of visible light (45%), it needs to develop or use novel visible light-responsive photocatalytic materials.

There are various types of metal oxide semiconductor that operate under visible light such as Fe2O3 (=2.1 eV), WO3 (=2.6 eV), SnO2 (=2.30 eV), Bi2O3 (=2.48 eV), Ag3PO4 (2.45 eV), CuO (indirect bandgap = 1.4 eV), and CuO (2.17 eV) [10, 11, 17, 18]. Among these metal oxides, Ag3PO4 is the preferable photocatalytic material because of its high photoefficiency than other aforementioned oxides. For instance, the quantum efficiency of Ag3PO4 is up to 90% at a wavelength greater than 420 nm and its extremely high photooxidative ability to split water to the evolution of oxygen (O2) and high organic dye removal under visible light irradiation [12, 13]. The reasons why Ag3PO4 have these mentioned benefits over other oxides are because of its novel atomic configurations and its metallic-like electronic structures. The reduction potential of H+/H2 is more negative than the conduction band edge potential of Ag3PO4. Consequently, Ag3PO4 may produce oxygen, not hydrogen. As a result of mentioned novel properties of Ag3PO4, it has been chosen as a candidate material for photocatalytic properties than other narrow bandgap semiconductors. Moreover, Yi et.al reported the first Ag3PO4 photocatalyst for degrading organic pollutants and splitting water [13, 14]. The schematic diagram of a photocatalytic mechanism of Ag3PO4 is shown in Figure 1.

Figure 1 shows that the conduction band edge potential of Ag3PO4 is more positive than the single-electron reduction process potential of -0.046 eV; thus, single-electron reduction for producing superoxide radicals (O2•−) did not take place on the conduction band of Ag3PO4. Under visible light irradiation on the Ag3PO4 catalyst, the electron-hole pairs were generated, and the electron was excited to the conduction band of Ag3PO4. The excess electron on the conduction band of Ag3PO4 facilitated a multioxidation reaction (2e− + O2 + 2H+ = H2O2), and it further react with single electrons (H2O2 + e− = OH•) to form hydroxide radicals; those radicals reacted with methylene blue dyes and decomposed it into CO2 and H2O. In addition to this, the combination of Ag2• ions with single electrons forms a black Ag nanoparticle which is the main reason for the instability and photocorrosion of Ag3PO4. In the second reaction, the hole reacted with H2O and formed OH• radicals while it has been reacted with dyes and decompose into carbon dioxide and water [15, 16]. However, the photocatalytic activity of Ag3PO4 is limited due to photocorrosion, high recombination rate, and instability in a solution [14, 19, 20]. In this review article, we discussed the possible means to enhance the degradation of organic pollutants from wastewater by using Ag3PO4. Finally, we discussed the future perspective of the Ag3PO4.

1.1. Structure of Ag3PO4 for Photocatalysis Activity.

Ma and coworkers reported the structural features and photocatalytic activity of the Ag3PO4 by using first-principle density functional theory (DFT) [21]. They investigated the energy band structure and density of the state of the Ag3PO4, which were essential for photocatalysis to harness solar energy for oxidizing water and degrading pollutants inside wastewater. The crystal structure of Ag3PO4 embraces isolated, regular PO4 tetrahedral with a P-O distance of ~1.539 angstroms (Å). The six Ag+ ions dispersed among twelve sites of 2-fold symmetry are shown in Figure 2. With the advancement of X-ray diffraction (XRD) technology, it established that it belongs to the body-centered cubic (bcc) structure type with a lattice parameter of 6.004 Å, and the space group is P43n [20]. The electronic structure was also studied by hybrid DFT to obtain the high photocatalytic efficiency of Ag3PO4.

The band structure edge had determined by Perdew-Burke-Ernzerhof’s (PBE) generalized gradient approximation techniques, and its magnified view is nearly Fermi-level depicted in the following Figures 3(a) and 3(b). Both valence band edge maximum (VBM) and conduction band edge minimum (CBM) are located at point G. Figure 3(b) ascribes that the direct bandgap is equal to 2.61 eV for Ag3PO4. The indirect bandgap is equivalent to 2.43 eV found between points G and M. Therefore, the Ag3PO4 is indirect band gap which is equal to 2.43 eV. As indicated in Figure 3(c), the valence band edge potential of Ag3PO4 = 2.67 eV vs. NHE is more positive than the oxidation potential of water (H2O/O2 (1.23 eV vs. NHE)), so it is attributed to the oxidation of water by a hole in the valance band to produce oxygen and oxidized organic pollutants. The conduction band edge minimum (CBM) is 0.24 eV which is more positive than H+/H2 and the single electron reaction process. As result, it is not produced hydrogen for energy production and superoxide radical (O2•−) for photodegradation [22]. Umezawa and coworkers showed that the conduction band edge minimum (CBEM) was composed of hybridized Ag (5s, 5p) along with some P (3s) orbitals, while the valance band edge (EVB) was composed of the hybridized (4d) orbitals of Ag and 2p orbitals of oxygen as indicated in Figure 3(c) [23]. Owing to this unique structure and properties of Ag3PO4, it is regarded as a good photocatalytic activity in visible light.

1.2. Factors Affecting the Photocatalysis Activity of Ag3PO4

The size, shape, and exposed facet of Ag3PO4 affect the photodegradation of organic dyes from aqueous solutions [24, 25]. Therefore, controlling the morphology and crystal facet of Ag3PO4 during synthesis has improved its photocatalysis efficiency [25]. Dong and a coworker reported the effect of different morphology of Ag3PO4 on photocatalytic activities. These morphologies such as branched, tetra-pod,
nanorod, and triangular were synthesized by the mixture of dimethyl flour (DMF) and water (H\textsubscript{2}O) solvent without using any kind of template materials under the different conditions as elucidated in Figure 4(a), and their SEM images revealed in Figure 4(b). The measured BET specific surfaces of different shapes are as follows: branched (18.9 m\textsuperscript{2}/g), tetrapod (3.35m\textsuperscript{2}/g), nanorod shaped (14.9 m\textsuperscript{2}/g), triangular-prism shaped (2.18m\textsuperscript{2}/g), and irregular spherical Ag\textsubscript{3}PO\textsubscript{4} (1.02m\textsuperscript{2}/g) surface area. The efficiency of degrading MB and RhB dyes was higher for branched ones since it has a high surface area to adsorb a large number of dyes which offered a high degradation ability of methylene blue (MB) and rhodamine blue (RhB) for branched as shown in Figures 5(a) and 5(b) [26].

Various shapes and facets of Ag\textsubscript{3}PO\textsubscript{4} crystals have different photocatalysis efficiency. For example, Bi and coworkers synthesize a single crystalline Ag\textsubscript{3}PO\textsubscript{4} dodecahedron with only \{110\} facets and cubes with \{100\} facets by facile precipitation methods as shown in Figure 6(a). The dodecahedron was synthesized by a reaction between CH\textsubscript{3}COOAg and Na\textsubscript{2}HPO\textsubscript{4} while the cubic was formed by a reaction between [Ag(NH\textsubscript{3})\textsubscript{2}]\textsuperscript{+} and Na\textsubscript{2}HPO\textsubscript{4}. As revealed in Figure 6(b), an SEM image of dodecahedrons of Ag\textsubscript{3}PO\textsubscript{4} microcrystals bounded by twelve (110) planes, but smooth corners and edges of cubic crystals enclosed by (100) planes. Furthermore, the evaluated photocatalytic performance of rhombic dodecahedrons was higher than cubes for the degradation of organic contaminants as shown in Figure 6(c), which may be due to the higher surface energy of (110) facets (1.31 J/m\textsuperscript{2}) than of \{100\} facets (1.12 J/m\textsuperscript{2}) which impart a high active site to adsorb organic dyes to degrade [27].

In addition to the above factors, catalyst dose, pH of the solution, and initial dye concentrations also have enormous impacts on photocatalysis efficiency [28]. The catalyst dose refers to the number of photocatalysts in the solutions. Thus, increasing catalyst dosage increases the active site on the surface of the catalyst which causes the formation of more
reactive species. As a result, the photodegradation activities increase with an increase in catalyst dosage till the optimum amount is reached; beyond this, the solution becomes turbid and prevented the solar light that reaching the active site, and therefore, degradation efficiency starts to decrease [29]. Furthermore, the dye degradation efficiency depends on the pH values of wastewater. At low pH values, the surface of the Ag₃PO₄ is protonated and becomes positively charged since the initial Ag₃PO₄ has a negative surface charge according to the analysis of its negative zeta potential by Huang et al. [21], and it is easily protonated. As a result, it is efficient to degrade negatively charged organic dyes. Similarly, at high pH values of the solution, the surface of the Ag₃PO₄ becomes negatively charged, and it is effective to degrade cationic dyes [22]. And also, an increase in initial dye concentration decreases the photocatalytic activities because covering the active site of Ag₃PO₄ resulted in low solar light available on the surface of the catalyst, and therefore, low reactive species were formed, thus causing low degradation percentage [23, 30]. As increasing irradiation times more electron-hole pairs were generated, and more reactive species were generated. As a result, the degradation efficiency is increasing with irradiation time [22].

2. Common Challenges to Enhancing Photocatalytic Activities of Ag₃PO₄ Nanoparticles

Figure 7 shows the common challenges to promoting the dye degradation efficiency of Ag₃PO₄. Photocorrosion, instability, and high recombination rate are the main challenges to enhancing the degradation efficiency of Ag₃PO₄. Photocorrosion reduces photocatalytic activities of Ag₃PO₄ by covering the active sites of Ag₃PO₄ with black silver metals. These black silver metals formed when the silver ions in an interstitial site of Ag₃PO₄ accept the excited electrons and then reduced them to silver metals. Then, those silver metals can cover the surface of Ag₃PO₄. As a result, the photocatalyst of Ag₃PO₄ declined [15]. Instability of Ag₃PO₄ is related to a decomposing of Ag₃PO₄ in an aqueous solution, at high thermal heating and long irradiated light, so instability or photocorrosion of Ag₃PO₄ is limited the use of Ag₃PO₄ in practical application [31]. The recombination rates of photoexcited electrons and holes of Ag₃PO₄ also reduce the photocatalytic activity of Ag₃PO₄ owing to there being no scavenger of electrons and holes to suppress the reunion photogenerated charge carriers.
Figure 4: (a) Schematic diagram of growth and mechanism of formation of various Ag₃PO₄ crystals under different conditions. (b) SEM images of the branch (A), tetrapod (B), nanorod (C), and triangular prism (D) Ag₃PO₄ crystals [26].
3. Methods for Enhancing Photocatalysis Activity of Ag₃PO₄

3.1. Loading Noble Metal on the Surface of Ag₃PO₄. Loading noble metal on the surface of Ag₃PO₄ is the method to enhance the photocatalytic activities of Ag₃PO₄ because the noble metal loaded on the surface of Ag₃PO₄ acts as an electron scavenger [32]. This means the excited electrons from the valence band are removed from the Ag₃PO₄ by noble metal so that there is no further recombination of charge carriers and suppresses photocorrosion because the excited electron does not get interstitial Ag⁺ ions to form black Ag metal covers the active sites of Ag₃PO₄ which is reducing the absorption of light and adsorption of dyes to the active site of Ag₃PO₄ and leads to depletion of photocatalytic activity to degradation dyes from aqueous solution [33]. For instance, Figure 8 shows that decorating of platinum (pt) on the surface of Ag₃PO₄ highly enhances the stability of Ag₃PO₄ which has exhibited better efficiency when it is used for six consecutive runs [34]. However, the performance of neat Ag₃PO₄ deteriorated when it had been used for a six repeating runs due to the gradual decomposition of Ag₃PO₄ to weakly active Ag nanoparticle which is the main cause for instability and photocorrosion of Ag₃PO₄ [34, 35].

The aforementioned advantages were accomplished as follows. The loaded noble metals on Ag₃PO₄ formed Schottky-type heterostructures as depicted in Figure 9(a). Since the contact between metal and semiconductor forms the Schottky barrier at their interface owing to the difference in work functions [36], the work function of Ag₃PO₄ conduction band edge (CBE), Au, Pd, and Pt is 4.95, 5.1, 5.12, and 5.65 eV, respectively [34, 37] since Ag₃PO₄ n-type semiconductor and its Fermi level are close to the conduction band edge. When noble metal contacts with Ag₃PO₄, the electrons flow from semiconductor to metals to attain two systems at the equilibrium, and a new Fermi level is established, and the internal electric field directed from Ag₃PO₄ to metal was formed. When the (Au, Pd, Pt)/Ag₃PO₄ heterostructure is imposed to visible light, the electron in the VB excited to CB and by forming a hole at VB, and electrons in the CB easily flow to metals owing to CB of Ag₃PO₄ at higher potential and also an internal electric field-assisted the flow electron from Ag₃PO₄ to metals. As result, the charge recombination rate and the instability of Ag₃PO₄ are effectively suppressed [34]. The electron reacted with oxygen and form O₂ reactive species that able to decompose organic pollutants. The holes left in VB have proceeded an oxidization reaction to decompose organic dyes as depicted in Figure 9(b).

In addition to those benefits, noble metal nanoparticles loaded on the surface of Ag₃PO₄ revealed remarkable enhancement absorption of both UV and visible light than pure Ag₃PO₄ as indicated in Figure 10. This can be the attribution of localized surface plasmon resonance effect (LSPR)
of noble metal loaded on the surface of Ag₃PO₄ in which a vibrational frequency of coming electromagnetic radiation matches with the vibration frequency of the electrons in the noble metals which help to harvest a large amount of coming light [38]. These have improved the photocatalytic activity of Ag₃PO₄ [34]. As shown in Table 1, many reported works on the loading of noble metal on surface Ag₃PO₄ to enhance the photocatalytic activities of Ag₃PO₄ are listed.

Different noble metals have a different effects on enhancing photocatalytic activities of Ag₃PO₄ because of their various specific properties. Figure 11(a) shows the enhancement of photocatalytic activities of the Ag₃PO₄ by loading noble metals, and a comparative study of the photocatalytic activities of various noble metals loaded on the surface of Ag₃PO₄ and with other photocatalyst materials. As indicated in this Figure 11(a), different noble metals loaded on Ag₃PO₄ show unequal performances because they do not have equal work functions. The large differences in work function between the noble metals and Ag₃PO₄ are necessary for a better photocatalytic process, because it facilitates a transfer of a
Figure 8: Continued.
photogenerated electron from Ag₃PO₄ to noble metals. So, the degrading ability of dyes by Pt/Ag₃PO₄ is larger than the other two noble metals due to Pt having a large work function difference with the conduction band edge of Ag₃PO₄ as shown in Figure 9(a) which highly assists the electron transfer from Ag₃PO₄ to Pt. As a result, the photo-degradation Pt loaded on Ag₃PO₄ is higher than the other two noble metals and bare Ag₃PO₄ [39]. In general, as indicated in Figure 11(a), the degradation of the dye by noble metal loaded on the surface of Ag₃PO₄ was better when compared to the bare one due to the aforementioned reason [34]. Moreover, Figure 11(b) shows that the efficiency of degrading different types of dyes by identical photocatalysts is not the same owing to the structure, and the surface charge difference has existed between the given dyes [40], and the surface charge of Ag₃PO₄ negative due to it has plenty OH (hydroxyl group) [41] which helped to adsorb highly cationic dyes.
Vacuum

\( \Phi_{(Ag)} = 4.26 \text{ eV} \)
\( \Phi_{(Au)} = 5.10 \text{ eV} \)
\( \Phi_{(Pd)} = 5.12 \text{ eV} \)
\( \Phi_{(Pt)} = 5.65 \text{ eV} \)

\( E_f (Ag) \)
\( E_c \)
\( E_f (Au) \)
\( E_f (Pd) \)
\( E_f (Pt) \)

\( E_f ('\text{new}') \)
\( h^+ \)
\( e^- \)

\( \text{Ag}_3\text{PO}_4 \)

\( \text{Au} \)
\( \text{Pd} \)
\( \text{Pt} \)

\( \text{O}_2 \)

\( \text{hv} (\text{Vis.}) \)

\( \text{Organic pollutants} \)

\( \text{Figure} 9: \) (a) Schottky-type heterostructures contact with noble metals. (b) Mechanism of electron transfer between Ag$\text{}_3\text{PO}_4$ and noble metals under visible light in organic solution [34].

\( \text{Figure} 10: \) UV-vis diffuse reflectance spectra of Ag$\text{}_3\text{PO}_4$ and M/Ag$\text{}_3\text{PO}_4$ [34].
3.2. Forming Binary Ag₃PO₄ Composite with Semiconductor and Supported Material. There are different methods to enhance the photocatalytic activity of a given semiconductor among as forming heterojunctions with another semiconductor [42], which is provided the following advantages to improve photocatalysis performance such as (1) reducing the recombination of photogenerated charge carriers by transferring electrons and holes between a junction, and as result, the formation of reactive oxidative species increased which was decontaminated organic dyes from wastewater [39]; (2) extending the absorption of solar light for large bandgap semiconductors when combined with small bandgap semiconductors [43]; (3) improve stability issue of a single component; and (4) forming nanoheterostructure semiconductors has a large surface area and enough active sites to adsorbed organic dyes.

Therefore, coupling Ag₃PO₄ with other semiconductors is among the methods to enhance the photocatalytic activities of Ag₃PO₄. The main advantageous form heterojunctions with Ag₃PO₄ are as follows: (i) solving instability issues and reducing the photocorrosion, (ii) improving the absorption of solar light in the visible range, and (iii) suppressing the recombination of charge carriers [39, 44, 45]. For instance, Figure 12 reveals the composite of Co₃O₄/Ag₃PO₄ in which a heterojunction was formed between Co₃O₄ and Ag loaded on Ag₃PO₄ in which silver metal appeared on the surface of Ag₃PO₄ during the photocatalysis process [44]. As indicated in this Figure 12, the photoexcited electrons and holes transferred Ag and Co₃O₄, respectively. As a result, there is no recombination of holes-electrons and photocorrosion because both charge carriers have not stayed on the Ag₃PO₄ after photoexcitation has been done. The solar absorption of mentioned heterojunction is better than a single component.

Bi and coworkers decorated the silver halides as core-shell on the surface of rhombic dodecahedral Ag₃PO₄ by the ion change method, and as we knew, the Ag₃PO₄ has rhombic dodecahedral morphology that has high surface energy which makes it dissolve in solution [45]. The intention of decorating Ag₃PO₄ is to prevent dissolution and enhance the stability of Ag₃PO₄ during photocatalyst activity since silver halides have lower solubility in aqueous solution than pristine Ag₃PO₄. As well as, the valance band and conduction band of all halides are less negative than Ag₃PO₄.
except Cl, so that the separation of charge carriers increases, and the recombination rate may be significantly reduced. In addition to this, the photocorrosion was inhibited for Ag (Br, I)/Ag₃PO₄ by facilitated multiple-electron reduction reaction of oxygen (O₂ + 2H⁺ + 2e⁻ = H₂O₂) [46] at Ag₃PO₄ without photo-reduction of silver ions into black silver metals. As a result, photodegradation of organic dyes by Ag₃PO₄ was enhanced as shown in Figure 13.

Supporting materials such as cellulose, graphene, and other porous materials have been used with Ag₃PO₄. These supporting materials increases the photocatalytic activities of Ag₃PO₄ by improving the surface area, morphology and reducing agglomerations of Ag₃PO₄. Based on this concept, Yang and coworkers synthesized Ag₃PO₄/graphene oxide nanocomposite by simple precipitation methods and subsequently reduced graphene oxide to reduce graphene to form Ag₃PO₄/reduced graphene oxide nanocomposite. As a result, the morphology and size were controlled according to synthesis techniques illustrated in Figure 14(a). In addition to these, the conductive property of graphene inhibited recombination e⁻·h⁺ pairs by charge transferring between Ag₃PO₄ and graphene as indicated in Figure 14(c). Due to the above reason, the photodegradation of organic dyes by Ag₃PO₄/graphene-based nanocomposite is excellent when compared to bare Ag₃PO₄ as shown in Figure 14(b). To check the stability of Ag₃PO₄ and Ag₃PO₄/GR, the XRD characterization was recorded according to Figure 14(d) after a photocatalysis activity. It is observed that Ag metals appeared for Ag₃PO₄ which is the main cause for photocorrosion but not appeared for composite owing to the electron in an Ag₃PO₄ transferring to graphene sheet as indicated in Figure 14(c) before it combined with Ag⁺ ions to form black silver metals. Therefore, combining Ag₃PO₄ with graphene-based materials has reduced photocorrosion to a large extent [47]. Further, Table 2 shows the lists of published works on Ag₃PO₄/metal oxide semiconductor or supporting materials for dye degradation.

The photocatalytic activity toward degradation of organic dyes from aqueous solution was also enhanced when Ag₃PO₄ was combined within a different dimension (1D, 2D, 3D) semiconductor materials [48] which were reviewed in the following Table 3. Various morphology of semiconductors offers special properties for the materials such as increased surface area by reducing agglomeration, increasing charge transferring between the junction for transporting and separation photogenerated electron-hole pairs, and serving as a superior template for hetero growth of Ag₃PO₄ [1, 49, 50].

3.3. Ag₃PO₄-Based Ternary Nanocomposite for Degrading Dyes from Wastewater. Ternary nanocomposite types of the composite are formed when three semiconductors that have matched band structures are combined, and also, ternary composite is formed when the binary composite is clumped together with supporting materials like graphene, cellulose, etc. In ternary composite, the synthesized materials have synergetic performance and properties of three single components thus resulting in highly inhibited recombination of charge carriers since the time of recombination has elongated by easily transferring charge carriers between the junction of three semiconductors. In addition to these, the stability and absorption of light are highly enhanced than single and binary components, and therefore, the photodegradation of organic dyes by ternary is higher than in single and binary materials [51].

So, forming Ag₃PO₄ containing ternary nanocomposites improved the degradation efficiency of Ag₃PO₄. Among these materials, one is the Ag₃PO₄. And other two materials are used to enhance the photostability and photocatalytic activities of Ag₃PO₄. Using ternary nanocomposites has resulted in a reduction in the consumption of expensive noble metals. Among the three ternary nanocomposites, one of them may be magnetic or supporting materials. The magnetic material enhances the photocatalytic activities as well as the recoverability of Ag₃PO₄. A typical example of the photocatalytic activities of ternary nanocomposites is shown in Figure 15. As revealed in Figure 15, the conduction band edge and valance band edge of WO₃ are more positive than the conduction band edge and valance band edge of Ag₃PO₄, and their bandgap is 2.44 eV and 2.35 eV for WO₃.
So, electron-hole pairs were generated under visible light for both semiconductors, and also, the electron migrates from Ag$_3$PO$_4$ CB (conduction band) to WO$_3$ CB (conduction band), and the hole migrated from the valance band (VB) of WO$_3$ to the valance band (VB) of Ag$_3$PO$_4$. After that, the holes oxidized organic dyes adsorbed on the surface of Ag$_3$PO$_4$, and the electrons were consumed via proceeding multioxidation reaction with

![Graph of Ag$_3$PO$_4$ and Ag$_3$PO$_4$/GR after photocatalysis](image)

**Figure 14:** (a) Schematic illustration of the synthesis of Ag$_3$PO$_4$ and Ag$_3$PO$_4$/graphene-based composite. (b) C/Co vs. time photodegradation RhB synthesized materials. (c) Photodegradation mechanisms in an Ag$_3$PO$_4$/GR composite under visible light. (d) XRD spectra of Ag$_3$PO$_4$ and Ag$_3$PO$_4$/GR after photo degradation [47].

| Catalyst Types of dyes | Efficiency (%) | Initial dye Conc. | Illumination light | References |
|------------------------|----------------|-------------------|-------------------|------------|
| Ag$_3$PO$_4$/ZnO       | MB             | 98.16% (30 min)   | —                 | Visible light [39] |
| Ag$_3$PO$_4$/cellulose | MO             | 90% under sun light (80 min) | 0.2 g/L | Sun light [61] |
| Ag$_3$PO$_4$/graphene  | MB             | 90% (20 min)      | 2.5 × 10$^{-3}$ M | Visible light [62] |
| Ag$_3$PO$_4$/TNS       | RhB            | 99.11% (50 min)   | 50 mg/L         | Sun light [63] |
| Co$_3$O$_4$/Ag$_3$PO$_4$| MB             | 100% (12 min)     | 10 mg/L         | Visible light [44] |
| N-doped carbon quantum dot/Ag$_3$PO$_4$ | MB | 100% (70 min) | 20 mg/L | Visible light [64] |
| g-C$_3$N$_4$/Ag$_3$PO$_4$ | MB | 96% (10 min) | 10 mg/L | Visible light [65] |

| Catalyst Types of dyes | Degradation efficiency | Dimension of semiconductor combined with Ag$_3$PO$_4$ | Initial dye Conc. (Co) | Illumination light | Reference |
|------------------------|-------------------------|-------------------------------------------------------|-------------------------|--------------------|-----------|
| Ag$_3$PO$_4$/MoS$_2$    | RhB                     | 90% (8 min)                                           | 2D graphene nanosheets | 20 mg/L           | Visible light [49] |
| Ag$_3$PO$_4$/TO$_2$     | RhB                     | 100% (7.5 min)                                        | 1D (nanofibers)        | 10 mg/L           | Visible light [66] |
| Ag$_3$PO$_4$/La$_2$Ti$_2$O$_7$ | RhB | 100% (8 min) | 2D (nanosheets) | 10 mg/L | UV/visible light [67] |
| Ag$_3$PO$_4$/CuO        | RhB                     | 100% (75 min)                                        | 3D (carambola-like nanostructure) | 1 × 10$^{-5}$ mol/L | Visible light [68] |
| Ag$_3$PO$_4$/TNS        | RhB                     | 99.11% (50 min)                                      | 2D (TiO$_2$ nanosheets) | 10 mg/L | Visible light [63] |
| g-C$_3$N$_4$/Ag$_3$PO$_4$ | MO                   | 3 times (Ag$_3$PO$_4$)                               | 2D (sheets)            | 10 mg/L           | Visible light [69] |
|                        |                         | 5 times (g-C$_3$N$_4$)                                |                         |                    |           |
| Ag$_3$PO$_4$/TiO$_2$    | Black liquor            | 60.4% (300 min)                                      | 1D (nanofibers)        | 30 mg/L           | Visible light [70] |
| Ag$_3$PO$_4$/PAN        | RhB                     | 100% (16 min)                                        | 1D (nanofibers)        | —                 | Visible light [71] |
Further, the produced H$_2$O$_2$ reacted with electrons and produced hydroxyl radical ($\cdot$OH) which participated degradation of organic dyes from aqueous solution, and the Fe$_2$O$_3$ in the composite acts as a mediator for electron transfer from Ag$_3$PO$_4$ to WO$_3$ and also its scale number of recyclability of catalyst for practical application [52]. Moreover, some of the lists of published articles on Ag$_3$PO$_4$ based on ternary nanocomposite for degradation of dyes are explained in Table 4.

And also, the magnetically separable Ag$_3$PO$_4$/CoFe$_2$O$_4$/GO composite reported by Chao and his coworkers was synthesized by an efficient precipitation method with different mass ratios of Ag$_3$PO$_4$ to CoFe$_2$O$_4$/GO. The Ag$_3$PO$_4$/CoFe$_2$O$_4$/GO composite showed better photocatalytic activity than bare Ag$_3$PO$_4$ under Ag$_3$PO$_4$/MG-15% conditions, 91% of MO is degraded, while under the same condition, only 36% of MO was degraded by the bare Ag$_3$PO$_4$ after 15 min of light irradiation, and also, Ag$_3$PO$_4$/CoFe$_2$O$_4$/GO shows good recyclability when compared to bare Ag$_3$PO$_4$ as evidenced in Figure 16(a) [53]. As explained in Figure 16(b) the photocatalytic mechanism of ternary is like the following. Firstly, the composite was irradiated with visible light; electrons were excited from VB to the CB in both CoFe$_2$O$_4$. At the same time, electrons transferred from CB of CoFe$_2$O$_4$ to CB of Ag$_3$PO$_4$ and reduced the oxygen adsorbed on the surface of the catalyst and formed O$_2$- radical, and holes transferred from the valance band of Ag$_3$PO$_4$ to the valance band of CoFe$_2$O$_4$. Superoxide (O$_2$-) radical degrades MO dyes. The holes simultaneous oxidize MO directly into carbon dioxide and water molecules and the photoreaction; the e−-h+ pairs could be separated with ease due to the high electron transfer capacity of GO [54].

The hierarchical Ag$_3$PO$_4$/TiO$_2$/Fe$_3$O$_4$ nanocomposite structure shows high photocatalytic activity, high stability, and good recyclability than Ag$_3$PO$_4$ toward degradation of AO7 dyes from wastewater due to high photogenerated charge separation which attribution of TiO$_2$ and Ag$^+$ ions that produced by photoinduced electron and inhibit the further decomposition of Ag$_3$PO$_4$. The Fe$_3$O$_4$ helps for...
separation after being used for photocatalytic activity. The performance achieved by this material is around 97% toward degradation of AO7 dyes [55]. Li et al. reported the ZnFe2O4-ZnO-Ag3PO4 hollow nanospheres synthesized by using phenolic formaldehyde microspheres as a template via an impregnating-calcination process. And it shows good photocatalytic activity toward mineralization of organic pollutants inside wastewater owing to the high surface area; small particle size is achieved. As shown in Figure 17, cascade electron transfer from CB of ZnFe3O4 to ZnO to Ag3PO4 is enhanced charge separation. And due to the small particle size that is difficult to separate after being used for photocatalysis activity, so by using external magnetic, it is easily separated because ZnFe3O4 has a magnetic property [56].

3.3.1. Photocatalysis Mechanisms in a Semiconductor to Decontaminate Organic Dyes. Photoreaction is essential to complete mineralization of organic pollutants from an aqueous solution at ambient temperature and pressure without introducing secondary pollutants. Under this part, we discussed the photoreaction pathway for any semiconductor materials used for photodegradation. The photodegradation of organic dyes is a redox reaction in which reduction reaction and oxidation reaction take place in the conduction and valance band, respectively. The process of photoreaction is divided into three steps. First, the electron (e-) and hole (h+) pairs are generated by photon energy greater than or equal to the bandgap of the semiconductor, and the electrons transfer from VB to CB by leaving a vacant electron site. And due to the small particle size that is difficult to separate after being used for photocatalysis activity, so by using external magnetic, it is easily separated because ZnFe3O4 has a magnetic property [56].

![Figure 17](image)

**Figure 17:** The cascade electron transfer from ZnFe3O4/ZnO/Ag3PO4 [56].

![Figure 16](image)

**Figure 16:** (a) Repeated photocatalytic experiments. (b) Proposed mechanism for degradation of MO dye with Ag3PO4/CoFe2O4/GO composite [53].
and hole reacted with oxygen and water to form superoxide radicals \((O_2^{-})\) and hydroxyl radicals \((\cdot OH)\), respectively, according to Equations (2) and (4). Further superoxide radicals reacted with \(H_2O\) and form hydroperoxyl radicals \((HO_2^{\cdot})\) according to (Equation (3)). Thirdly, these formed superoxide radicals \((O_2^{-})\), hydroxyl radicals \((\cdot OH)\), and hydroperoxyl radicals \((HO_2^{\cdot})\) oxidized organic dyes and converted them into \(CO_2\) and \(H_2O\) which is not a secondary pollutant. The overall mechanisms of photodegradation of organic dyes are elucidated in Figure 18 [57].

\[
\text{Semiconductor} + hv \ (eV) \rightarrow e^- + h^+ \quad (1)
\]
\[
O_2 + e^- \rightarrow O_2^{-} \quad (2)
\]
\[
O_2^{-} + H_2O \rightarrow HO_2^{\cdot} \quad (3)
\]
\[
H_2O/\cdot OH + h^+ \rightarrow \cdot OH \quad (4)
\]
\[
O_2^{-}/HO_2^{\cdot}, \cdot OH + OPs \rightarrow CO_2 + H_2O \quad (5)
\]

3.3.2. Future Perspective and the Opinion of the Reviewer. All the mentioned methods had been used as supportive material to reduce the limitation of the \(Ag_3PO_4\) which are photocorrosion, instability, and high recombination rate. However, they have not stated the cost of a precursor used to synthesize \(Ag_3PO_4\), but the precursor used for fabricated \(Ag_3PO_4\) is expensive. So, we will suggest that replacing the \(Ag_3PO_4\) precursor with a less-cost precursor will improve the availability and efficiency of \(Ag_3PO_4\) for photocatalysis applications. Especially, extracting a precursor from waste-by-products and naturally occurring materials enhances the nobility and application of \(Ag_3PO_4\) for photodegradation. For instance, eggshells (ES) and bones are rich in phosphate so we can use them as precursors for synthesizing \(Ag_3PO_4\). Synthesizing of \(Ag_3PO_4\)/supporting materials used to reduce agglomeration. For instance, silicate can be extracted from bagasse ash which is a by-product of sugar cane because it is cost-wise and available everywhere in the sugar industry. Doping of large bandgap semiconductors such as \(ZnO\) and \(TiO_2\) is crucial to reducing the wideband to narrow bandgap that enables them to harvest the visible light while a couple with \(Ag_3PO_4\). Thus, the doped wide-bandgap oxides not only reduce the limitation of the \(Ag_3PO_4\) but also actively participate in the degradation of the organic dyes in the wastewater.

4. Conclusion

Nano-scaled metal oxide semiconductors have many applications due to their unique properties. The photocatalyst is among the wastewater treatment methods, where nano-scaled semiconductors have been used as a catalyst. Among the metal oxide semiconductors, \(Ag_3PO_4\), gain significant attention due to its lower bandgap and visible light-absorbing efficiency of up to 95%. However, due to high photocorrosion, instability, and high recombination rate, the photocatalytic activities of \(Ag_3PO_4\) are getting lower. Such factors which hinder the photocatalytic activity of \(Ag_3PO_4\) can be overcomed by using Noble metal loaded \(Ag_3PO_4\), forming binary composition such as \(Ag_3PO_4/metal\) oxides or supporting materials, \(Ag_3PO_4\)-based ternary nanocomposite and changing the morphology of \(Ag_3PO_4\). From all the possible approaches, the mentioned limitations of \(Ag_3PO_4\) were minimized, and the degradation efficiency of the organic dyes in the wastewater was enhanced. Therefore, the \(Ag_3PO_4\) with reduced photocorrosion, instability, and recombination rate is a promising agent to degrade organic dye from wastewater.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] S. Shenoy, S. Ahmed, I. M. C. Lo, S. Singh, and K. Sridharan, “Rapid sonochemical synthesis of copper doped ZnO grafted on graphene as a multi-component hierarchically structured visible-light-driven photocatalyst,” Materials Research Bulletin, vol. 140, article 111290, 2021.
[2] C. A. Martinez-Huitle and E. Brillas, “Decontamination of wastewaters containing synthetic organic dyes by electrochemical methods: a general review,” Applied Catalysis B: Environmental, vol. 87, no. 3-4, pp. 105–145, 2009.
[3] S. Shenoy, K. Taraferd, and K. Sridharan, “Bimetallic nanoparticles grafted ZnO hierarchical structures as efficient visible light driven photocatalyst: an experimental and theoretical
study,” *Journal of Molecular Structure*, vol. 1236, article 130355, 2021.

[4] J. Acharya, J. N. Sahu, B. K. Sahoo, C. R. Mohanty, and B. C. Meikap, “Removal of chromium(VI) from wastewater by activated carbon developed from Tamarind wood activated with zinc chloride,” *Chemical Engineering Journal*, vol. 150, no. 1, pp. 25–39, 2009.

[5] J. Hollender, S. G. Zimmermann, S. Koepke et al., “Elimination of organic micropollutants in a municipal wastewater treatment plant upgraded with a full-scale post-ozonation followed by sand filtration,” *Environmental Science & Technology*, vol. 43, no. 20, pp. 7862–7869, 2009.

[6] A. Y. Zahrim and N. Hilal, “Treatment of highly concentrated dye solution by coagulation/flocculation-sand filtration and nanofiltration,” *Water Resources and Industry*, vol. 3, pp. 23–34, 2013.

[7] M. Elsayed and M. E.-S. Abdel-Raouf, “Wastewater treatment methodologies, Review Article,” *Int J Environ & Agri Sci*, vol. 3, p. 18, 2019.

[8] S.-Y. Lee and S.-J. Park, “TiO2 photocatalyst for water treatment applications,” *Journal of Industrial and Engineering Chemistry*, vol. 19, no. 6, pp. 1761–1769, 2013.

[9] N. N. Fathima, R. Aravindhan, J. R. Rao, and B. U. Nair, “Dye house wastewater treatment through advanced oxidation process using Cu-exchanged Zelite: a heterogeneous catalytic approach,” *Chemosphere*, vol. 70, no. 6, pp. 1146–1151, 2008.

[10] A. Ibhadon and P. Fitzpatrick, “Heterogeneous photocatalysis: recent advances and applications,” *Catalysts*, vol. 3, no. 1, pp. 189–218, 2013.

[11] H. Chen and L. Wang, “Nanostructure sensitization of transition metal oxides for visible-light photocatalysis,” *Beilstein Journal of Nanotechnology*, vol. 5, pp. 696–710, 2014.

[12] A. Fujishima and K. Honda, “Electrochemical photolysis of water at a semiconductor electrode,” *Nature*, vol. 238, no. 5358, pp. 37–38, 1972.

[13] Z. Yi, J. Ye, N. Kikugawa et al., “An orthophosphatase semiconductor with photooxidation properties under visible-light irradiation,” *Nature Materials*, vol. 9, no. 7, pp. 559–564, 2010.

[14] J. Li, X. Ji, X. Li et al., “Preparation and photocatalytic degradative performance of Ag3PO4 with a two-step approach,” *Applied Surface Science*, vol. 372, pp. 30–35, 2016.

[15] Y. Luo, N. Xu, X. Liu, L. Yang, H. Wu, and Y. Qin, “Photoactivity enhanced and photo-corrosion inhibited Ag3PO4/ZnO visible light photocatalyst for the degradation of rhodamine B,” *Energy and Environment Focus*, vol. 4, no. 2, pp. 121–127, 2015.

[16] J.-D. Wang, F. R. Wang, J. K. Liu, X. H. Yang, and X. H. Zhong, “Controlled synthesis and characterizations of thermostabilized Ag3PO4 crystals,” *Research on Chemical Intermediates*, vol. 42, no. 12, pp. 8285–8304, 2016.

[17] S. Thangaraj Nishanthi, *Photocatalytic Functional Materials for Environmental Remediation*, John Wiley & Sons Inc, 2019.

[18] P. Riente and T. Noël, “Application of metal oxide semiconductors in light-driven organic transformations,” *Catalysis Science & Technology*, vol. 9, no. 19, pp. 5186–5232, 2019.

[19] G. Kiriaidkis and V. Binas, “Metal oxide semiconductors as visible light photocatalysts,” *Journal of the Korean Physical Society*, vol. 65, no. 3, pp. 297–302, 2014.

[20] X. Ma, B. Lu, D. Li, R. Shi, C. Pan, and Y. Zhu, “Origin of photocatalytic activation of silver orthophosphate from first-principles,” *The Journal of Physical Chemistry C*, vol. 115, no. 11, pp. 4680–4687, 2011.

[21] K. Huang, Y. Lv, W. Zhang et al., “One-step synthesis of Ag3PO4/Ag photocatalyst with visible-light photocatalytic activity,” *Materials Research*, vol. 18, no. 5, pp. 939–945, 2015.

[22] A. M. Taddesse, M. Alemu, and T. Kebede, “Enhanced photocatalytic activity of p-n-heterojunction ternary composite Cu2O/ZnO/Ag3PO4 under visible light irradiation,” *Journal of Environmental Chemical Engineering*, vol. 8, no. 5, 104356, 2020.

[23] K. M. Reza, A. S. W. Kurny, and F. Gulshan, “Parameters affecting the photocatalytic degradation of dyes using TiO2: a review,” *Applied Water Science*, vol. 7, no. 4, pp. 1569–1578, 2017.

[24] Y. Bi, H. Hu, S. Ouyang, Z. Jiao, G. Lu, and J. Ye, “Selective growth of metallic Ag nanocrystals on Ag3PO4 submicro-cubes for photocatalytic applications,” *Chemistry - A European Journal*, vol. 18, no. 45, pp. 14272–14275, 2012.

[25] T. A. Vu, C. D. Dao, T. T. T. Hoang et al., “Highly photocatalytic activity of novel nano-sized Ag3PO4 for rhodamine B degradation under visible light irradiation,” *Materials Letters*, vol. 92, pp. 57–60, 2013.

[26] P. Dong, Y. Wang, H. Li, H. Li, X. Ma, and L. Han, “Shape-controllable synthesis and morphology-dependent photocatalytic properties of Ag3PO4 crystals,” *Journal of Materials Chemistry A*, vol. 1, no. 5, p. 4651, 2013.

[27] Y. Bi, S. Ouyang, N. Umezawa, J. Cao, and J. Ye, “Facet effect of single-crystalline Ag3PO4 sub-microcrystals on photocatalytic properties,” *Journal of the American Chemical Society*, vol. 133, no. 17, pp. 6490–6492, 2011.

[28] A. Kumar, “A review on the factors affecting the photocatalytic degradation of hazardous materials,” *Material Science & Engineering International Journal*, vol. 1, no. 3, 2017.

[29] H. M. Coleman, V. Vimonsees, G. Leslie, and R. Amal, “Degradation of 1,4-dioxane in water using TiO2 based photocatalytic and H2O2/UV processes,” *Journal of Hazardous Materials*, vol. 146, no. 3, pp. 496–501, 2007.

[30] M. Al Kausar, S. S. Gupta, and D. Chakrabortty, “Ag3PO4-based nanocomposites and their applications in photodegradation of toxic organic dye contaminated wastewater: review on material design to performance enhancement,” *Journal of Saudi Chemical Society*, vol. 24, no. 1, pp. 20–41, 2020.

[31] J. Tang, R. Meng, Q. Wang, S. Zhang, and Q. Li, “Fabrication and photocatalytic activity of Ag3PO4/T-ZnOw heterostructures,” *Nanoscale Research Letters*, vol. 15, no. 1, p. 131, 2020.

[32] H. Einaga, F. Futamura, and T. Ibusuki, “Complete oxidation of benzene in gas phase by platinized titania photocatalysts,” *Environmental Science & Technology*, vol. 35, no. 9, pp. 1880–1884, 2001.

[33] Y. Bi, H. Hu, S. Ouyang, Z. Jiao, G. Lu, and J. Ye, “Selective growth of Ag3PO4 submicro-cubes on Ag nanowires to fabricate necklace-like heterostructures for photocatalytic applications,” *Nanoscale Research Letters*, vol. 15, no. 1, pp. 3720, 2019.

[34] H. Wang, Y. Bai, J. Yang, X. Lang, J. Li, and L. Guo, “A facile way to rejuvenate Ag3PO4 as a recyclable highly efficient
photocatalyst,” *Chemistry*, vol. 18, no. 18, pp. 5524–5529, 2012.

[36] H. Chen, S. Chen, X. Quan, H. Yu, H. Zhao, and Y. Zhang, “Fabrication of TiO$_2$–Pt coaxial nanotube array Schottky structures for enhanced photocatalytic degradation of phenol in aqueous solution,” *The Journal of Physical Chemistry C*, vol. 112, no. 25, pp. 9285–9290, 2008.

[37] P. Dong, Y. Wang, B. Cao et al., “Ag$_3$PO$_4$/reduced graphite oxide sheets nanocomposites with highly enhanced visible light photocatalytic activity and stability,” *Applied Catalysis B: Environmental*, vol. 132-133, pp. 45–53, 2013.

[38] J. Li, Z. Lou, and B. Li, “Nanostructured materials with localized surface plasmon resonance for photocatalysis,” *Chinese Chemical Letters*, vol. 33, no. 3, pp. 1154–1168, 2022.

[39] Y. Yu, B. Yao, Y. He, B. Cao, Y. Ren, and Q. Sun, “Piezoelectric enhanced photodegradation of organic pollutants on Ag$_3$PO$_4$/ZnO nanowires using visible light and ultrasonic,” *Applied Surface Science*, vol. 528, article 146819, 2020.

[40] A. Kudo, K. Omori, and H. Kato, “A novel aqueous process for preparation of crystal form-controlled and highly crystalline BiVO$_4$ powder from layered vanadates at room temperature and its photocatalytic and photophysical properties,” *Journal of the American Chemical Society*, vol. 121, no. 49, pp. 11459–11467, 1999.

[41] Q. Liang, Y. Shi, W. Ma, Z. Li, and X. Yang, “Enhanced photocatalytic activity and structural stability by hybridizing Ag$_3$PO$_4$ nanospheres with graphene oxide sheets,” *Physical Chemistry Chemical Physics*, vol. 14, no. 45, pp. 15657–15665, 2012.

[42] H. Li, H. Hu, C. Bao et al., “Forming heterojunction: an effective strategy to enhance the photocatalytic efficiency of a new metal-free organic photocatalyst for water splitting,” *Scientific Reports*, vol. 6, no. 1, p. 29327, 2016.

[43] L. Zhou, W. Zhang, L. Chen, and H. Deng, “Z-scheme mechanism of photogenerated carriers for hybrid photocatalyst Ag$_3$PO$_4$/g-C$_3$N$_4$ in degradation of sulfamethoxazole,” *Journal of Colloid and Interface Science*, vol. 487, pp. 410–417, 2017.

[44] C. Tang, E. Liu, J. Wan, X. Hu, and J. Fan, “Co$_3$O$_4$ nanoparticle decorated Ag$_3$PO$_4$ tetrapods as an efficient visible-light-driven heterojunction photocatalyst,” *Applied Catalysis B: Environmental*, vol. 181, pp. 707–715, 2016.

[45] Y. Bi, S. OuYang, J. Cao, and J. Ye, “Facile synthesis of rhombic dodecahedral AgX/Ag$_3$PO$_4$ (X = Cl, Br, I) heterocrystals with enhanced photocatalytic properties and stabilities,” *Physical Chemistry Chemical Physics*, vol. 13, no. 21, pp. 10071–10075, 2011.

[46] H. Hu, Z. Jiao, T. Wang, J. Ye, G. Lu, and Y. Bi, “Enhanced photocatalytic activity of Ag/Ag$_3$PO$_4$ coaxial hetero-nano-wires,” *Journal of Materials Chemistry A*, vol. 1, no. 36, p. 10612, 2013.

[47] X. Yang, H. Cui, Y. Li, J. Qin, R. Zhang, and H. Tang, “Fabrication of Ag$_3$PO$_4$/graphene composites with highly efficient and stable visible light photocatalytic performance,” *ACS Catalysis*, vol. 3, no. 5, pp. 363–369, 2013.

[48] S. Shenoy, E. Jang, T. J. Park, C. S. Gopinath, and K. Sridharan, “Cadmium sulfide nanostructures: influence of morphology on the photocatalytic degradation of erioglaucine and hydrogen generation,” *Applied Surface Science*, vol. 483, pp. 696–705, 2019.

[49] P. Wang, P. Shi, Y. Hong, X. Zhou, and W. Yao, “Facile deposition of Ag$_3$PO$_4$ on graphene-like MoS$_2$ nanosheets for highly efficient photocatalysis,” *Materials Research Bulletin*, vol. 62, pp. 24–29, 2015.

[50] K. Sridharan, S. Shenoy, S. G. Kumar, C. Terashima, A. Fujishima, and S. Pitchaimuthu, “Advanced two-dimensional heterojunction photocatalysts of stoichiometric and non-stoichiometric bismuth oxyhalides with graphitic carbon nitride for sustainable energy and environmental applications,” *Catalysts*, vol. 11, no. 4, p. 426, 2021.

[51] P. Zhu, M. Hu, M. Duan, L. Xie, and M. Zhao, “High visible light response Z-scheme Ag$_3$PO$_4$/g-C$_3$N$_4$/ZnO composite photocatalyst for efficient degradation of tetracycline hydrochloride: preparation, properties and mechanism,” *Journal of Alloys and Compounds*, vol. 840, article 155714, 2020.

[52] H. B. Gasmalla, X. Lu, M. I. Shinger, L. Ni, A. N. Chishiti, and G. Diao, “Novel magnetically separable of Fe$_3$O$_4$/Ag$_3$PO$_4$@WO$_3$ nanocomposites for enhanced photocatalytic and antibacterial activity against Staphylococcus aureus (S. aureus),” *Journal of Nanobiotechnology*, vol. 17, no. 1, p. 58, 2019.

[53] Z. Liu, H. Feng, S. Xue et al., “The triple-component Ag$_3$PO$_4$-CoFe$_2$O$_4$-GO synthesis and visible light photocatalytic performance,” *Applied Surface Science*, vol. 458, pp. 880–892, 2018.

[54] D. Chao, Y. Liu, and Z. Zhu, “Facile fabrication of magnetically separable Ag$_3$PO$_4$/CoFe$_2$O$_4$/GO composites with enhanced visible light photocatalytic performance,” *Materials Letters*, vol. 217, pp. 239–242, 2018.

[55] J. W. Xu, Z. D. Gao, K. Han, Y. Liu, and Y. Y. Song, “Synthesis of magnetically separable Ag$_3$PO$_4$/TiO$_2$/Fe$_3$O$_4$ heterostructure with enhanced photocatalytic performance under visible light for photoinactivation of bacteria,” *ACS Applied Materials & Interfaces*, vol. 6, no. 17, pp. 15122–15131, 2014.

[56] N. Azbar, T. Yonar, and K. Kestioglu, “Comparison of various advanced oxidation processes and chemical treatment methods for COD and color removal from a polyester and acetate fiber dyeing effluent,” *Chemosphere*, vol. 55, no. 1, pp. 35–43, 2004.

[57] J. Madhavan, J. Theerthagiri, D. Balaji, S. Sunita, Choi, and M. Ashokkumar, “Hybrid advanced oxidation processes involving ultrasound: an overview,” *Molecules*, vol. 24, no. 18, p. 3341, 2019.

[58] J. J. Liu, X. L. Fu, S. F. Chen, and Y. F. Zhu, “Electronic structure and optical properties of Ag$_3$PO$_4$ photocatalyst calculated by hybrid density functional method,” *Applied Physics Letters*, vol. 99, no. 19, article 191903, 2011.

[59] A. Malathi, J. Madhavan, M. Ashokkumar, and P. Arunchalam, “A review on BiVO$_4$ photocatalyst: activity enhancement methods for solar photocatalytic applications,” *Applied Catalysis A: General*, vol. 555, pp. 47–74, 2018.

[60] W. Teng, X. Li, Q. Zhao, J. Zhao, and D. Zhang, “In situ capture of active species and oxidation mechanism of RhB and MB dyes over sunlight-driven Ag$_3$PO$_4$/plasmonic nanocatalyst,” *Applied Catalysis B: Environmental*, vol. 125, pp. 538–545, 2012.

[61] L. Lebogang, R. Bosigo, K. Lefatshe, and C. Muiva, “Ag$_3$PO$_4$/nanocellulose composite for effective sunlight driven photodegradation of organic dyes in wastewater,” *Materials Chemistry and Physics*, vol. 236, article 121756, 2019.

[62] Q. Xiang, D. Lang, T. Shen, and F. Liu, “Graphene-modified nanosized Ag$_3$PO$_4$ photocatalysts for enhanced visible-light photocatalytic activity and stability,” *Applied Catalysis B: Environmental*, vol. 162, pp. 196–203, 2015.
[63] P. Wang, Y. Li, Z. Liu et al., "In-situ deposition of Ag$_3$PO$_4$ on TiO$_2$ nanosheets dominated by (001) facets for enhanced photocatalytic activities and recyclability," *Ceramics International*, vol. 43, no. 15, pp. 11588–11595, 2017.

[64] C. Zhu, Y. Zhao, L. Fang et al., "N-doped carbon quantum dots/Ag$_3$PO$_4$ hybrid materials with improved visible light photocatalytic activity and stability," *Materials Letters*, vol. 188, pp. 304–307, 2017.

[65] J. Zhang, J. Lv, K. Dai, Q. Liu, C. Liang, and G. Zhu, "Facile and green synthesis of novel porous g-C$_3$N$_4$/Ag$_3$PO$_4$ composite with enhanced visible light photocatalysis," *Ceramics International*, vol. 43, no. 1, pp. 1522–1529, 2017.

[66] J. Xie, Y. Yang, H. He et al., "Facile synthesis of hierarchical Ag$_3$PO$_4$/TiO$_2$ nanofiber heterostructures with highly enhanced visible light photocatalytic properties," *Applied Surface Science*, vol. 355, pp. 921–929, 2015.

[67] S. Wan, F. Qi, W. Jin et al., "Construction of ultrafine Ag$_3$PO$_4$ nanoparticle and La$_2$Ti$_2$O$_7$ nanosheet 0D/2D heterojunctions with improved photocatalytic performance," *Journal of Alloys and Compounds*, vol. 740, pp. 901–909, 2018.

[68] P. Ma, Y. Yu, J. Xie, and Z. Fu, "Ag$_3$PO$_4$/CuO composites utilizing the synergistic effect of photocatalysis and Fenton-like catalysis to dispose organic pollutants," *Advanced Powder Technology*, vol. 28, no. 11, pp. 2797–2804, 2017.

[69] S. Kumar, T. Surendar, A. Baruah, and V. Shanker, "Synthesis of a novel and stable g-C$_3$N$_4$-Ag$_3$PO$_4$ hybrid nanocomposite photocatalyst and study of the photocatalytic activity under visible light irradiation," *Journal of Materials Chemistry A*, vol. 1, no. 17, p. 5333, 2013.

[70] L. Cai, Q. Long, and C. Yin, "Synthesis and characterization of high photocatalytic activity and stable Ag$_3$PO$_4$/TiO$_2$ fibers for photocatalytic degradation of black liquor," *Applied Surface Science*, vol. 319, pp. 60–67, 2014.

[71] H. Yu, Z. Jiao, H. Hu, G. Lu, J. Ye, and Y. Bi, "Fabrication of Ag$_3$PO$_4$-PAN composite nanofibers for photocatalytic applications," *CrystEngComm*, vol. 15, no. 24, p. 4802, 2013.

[72] M. Al Kausor and D. Chakrabortty, "Facile fabrication of N-TiO$_2$/Ag$_3$PO$_4$@GO nanocomposite toward photodegradation of organic dye under visible light," *Inorganic Chemistry Communications*, vol. 116, article 107907, 2020.

[73] X. C. Song, Y. L. Qi, Y. F. Zheng, J. N. Liu, and H. Y. Yin, "Construction of magnetic Fe$_3$O$_4$@C@Ag$_3$PO$_4$ nanocomposites with excellent visible photocatalytic performance," *Journal of Nanoscience and Nanotechnology*, vol. 17, no. 2, pp. 1407–1412, 2017.

[74] J. Li, Z. Liu, and Z. Zhu, "Enhanced photocatalytic activity in ZnFe$_2$O$_4$-ZnO- Ag$_3$PO$_4$ hollow nanospheres through the cascaded electron transfer with magnetic separation," *Journal of Alloys and Compounds*, vol. 636, pp. 229–233, 2015.

[75] S. Mosleh, M. R. Rahimi, M. Ghaedi, K. Dashtian, S. Hajati, and S. Wang, "Ag$_3$PO$_4$/AgBr/Ag-HKUST-1-MOF composites as novel blue LED light active photocatalyst for enhanced degradation of ternary mixture of dyes in a rotating packed bed reactor," *Chemical Engineering and Processing: Process Intensi- fication*, vol. 114, pp. 24–38, 2017.

[76] N. Güy, K. Atacan, E. Karaca, and M. Özacar, "Role of Ag$_3$PO$_4$ and Fe$_3$O$_4$ on the photocatalytic performance of magnetic Ag$_3$PO$_4$/ZnO/Fe$_3$O$_4$ nanocomposite under visible light irradiation," *Solar Energy*, vol. 166, pp. 308–316, 2018.