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PII:	S1387-7003(21)00397-X
DOI:	https://doi.org/10.1016/j.inoche.2021.108842
Reference:	INOCHE 108842
To appear in:	Inorganic Chemistry Communications
Received Date:	11 May 2021
Revised Date:	31 July 2021
Accepted Date:	1 August 2021



Please cite this article as: R. Nejat, Z. Najminejad, F. Fazlali, S. Shahraki, Z. Khazaee, $g-C_3N_4/H_3PW_4Mo_8O_{40}$ S-scheme photocatalyst with enhanced photocatalytic oxidation of alcohols and sulfides, *Inorganic Chemistry Communications* (2021), doi: https://doi.org/10.1016/j.inoche.2021.108842

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g-C₃N₄/H₃PW₄Mo₈O₄₀ S-scheme photocatalyst with enhanced photocatalytic oxidation of alcohols and sulfides

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Razieh Nejat: <u>0000-0001-8742-2342</u> Zohreh Najminejad: <u>0000-0002-3676-3101</u> Farnaz Fazlali :<u>0000-0001-6220-4058</u> Somaye Shahraki: <u>0000-0002-0597-4459</u> Abstract. In this work, graphitic carbon nitride $(g-C_3N_4)$ decorated with molybdenum-substituted tungstophosphoric acid as a novel photocatalyst $(H_3PW_4Mo_8O_{40}/g-C_3N_4)$ was used to catalyze the oxidation of alcohols and $(PW_4Mo_8/g-C_3N_4)$ displays sulfides. $H_3PW_4Mo_8O_{40}/g-C_3N_4$ higher photocatalytic activity under visible light irradiation for the oxidation of alcohols and sulfides compared with Keggin/g-C₃N₄ (PW₁₂/g-C₃N₄). To obtain the optimum value, molybdenum substitution contents (H₃PW_{12-x}Mo_xO₄₀) were changed from x = 4 to 12. The results showed that PW₄Mo₈ produces the best yield under visible-light irradiation. The results showed that PW₄Mo₈ was the best sample. The reaction rate increase can be due to the redox and acid properties of PW₄Mo₈/g-C₃N₄. This study provides a new insight for the preparation of highly efficient photocatalysts for the oxidation of organic compounds.

Keywords: Heteropolyacid, g-C₃N₄, Photocatalyst, Oxidation.

Running title: molybdenum-substituted tungstophosphoric $acid/g-C_3N_4$ as photocatalyst.

Highlights

- ✓ Designing a new set of HPAs as photocatalyst under visible-light.
- Proving the promising role of Mo cations in selective photocatalytic oxidation of alcohols and sulfides.
- ✓ The g-C₃N₄ with electronic structural property as visible-light active photocatalyst

Introduction

Recently, water pollution treatment has attracted the increasing attention of researchers. There are many water treatment technologies, like adsorption [1], Microwave [2,3], extraction [4], oxidation [5], and photo-oxidation [6] which are used to eliminate pollutants. Compared with other advanced oxidation technologies, photocatalysis was considered to be a more promising technology for transforming organic pollutants into harmless substances [7].

on the other hand, The Selective Oxidation of alcohols and sulfides to the corresponding carbonyl compounds and sulfoxides represent key reactions in the field of synthetic organic chemistry [8-18]. Sulfoxides have received enormous interest as chiral auxiliaries in organic synthesis, as useful building blocks to produce various chemically, biologically, and medicinally active molecules [19-21]. Several types of oxidizing agents, such as toxic metal oxides and peroxides, and methods have been used for the oxidation of alcohols and sulfides in solution and solid phases [22-29]. Many of these reagents and catalysts suffer from certain drawbacks such as the toxicity of the transition metals and environmentally harmful waste by-products, long reaction times, low selectivity, poor yields of products, and over-oxidation of the sulfoxides and aldehydes to sulfones and Carboxylic acids as side-reaction [30-32]. Therefore, in order to oxidation of sulfides and alcohols to sulfoxides and carbonyl compounds without excessive oxidation to sulfones and carboxylic acids, there is a demand for environmental-economic methods. Over the past few decades, significant attention has been paid to selective oxidation photocatalysts. Recently, numerous research on discovering new photocatalytic materials has been undertaken that are both more effectual and innately active under visible light [33-37]. Visible light has attracted wide attention with its clean and abundant advantages [38]. In this regard, photocatalysis using semiconductors is as ZnO [39],

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TiO2 [40], metal-organic frameworks [41, 42], heteropoly acids (HPAs) [43], and $g-C_3N_4$ nanaosheets [44, 45], is an efficient approach for oxidation reactions such. Among these compounds, heteropoly acids show high efficiency due to the redox and acidity properties. The dodecatunvgstophosphoric acid, $H_3PW_{12}O_{40}$ could show photocatalytic activity under visible light [46].

Recently tungesto- and molybo-phosphoric acids draw attention in photocatalytic reactions. For example, Fazlali et al. [47] explored Keggin hetero polyacid supported on BN and C₃N₄ as an efficient catalyst in the methanol photocatalytic dehydration reaction. Also, the ion-exchange in Keggin type HPAs (W and Mo) lead to improve the catalytic properties of the catalysts because the substitution of these atoms changes their acid and redox properties [48-50]. Unfortunately, low charge separation and high solubility in polar media hinder its practical utilization at a large scale. Recent studies have shown that the recombination of photogenerated electrons and holes can be controlled by coupling HPAs with an ideal substrate [51, 52]. In this perspective, for the anchoring of HPAs, graphitic carbon nitride $(g-C_3N_4)$ can be an appropriate candidate because of the presence of various functional groups and their unique properties. Graphitic carbon nitrides as the most stable allotrope of carbon nitride with high chemical and thermal stability and also unique electronic structure, have been standing in the hot research area for their potential applications in photocatalysis [53-55]. Also, g-C₃N₄ has rich surface properties that are attractive for catalysis applications due to the presence of basic surface sites. Besides, the band gap of g-C₃N₄ is 2.85 eV, with valence band (VB) and conduction band (CB) positions respectively at -1.1 and +1.6 eV. The $g-C_3N_4$ with this electronic structural property can be visible-light active photocatalyst [56]. Results show that the pure g-C₃N₄ almost exhibits no photocatalytic performance during the photocatalytic process, however, PMO/g-C₃N₄ composite exhibits excellent photocatalytic

performance because the step-scheme heterojunction promotes the separation of photoexcited electron-hole pairs [57, 58, 64]. In an S-scheme heterojunction, the powerful photogenerated electrons and holes are reserved in the CB of RP and VB of OP, respectively, while the pointless photogenerated charge carriers are recombined, introducing a strong redox potential. Also, in these catalysts, three factors: the internal electric field, band bending, and Coulombic attraction, act as the driving forces for the recombination of electrons in the CB of oxidation photocatalyst and holes in the VB of reduction photocatalysts [59-61]. The present work deals with the preparation of $PW_4Mo_8/g-C_3N_4$ as a stable and efficient stepscheme photocatalyst for the oxidation of sulfides and alcohols to sulfoxides and carbonyl compounds under visible light. We found that the stability and photocatalytic activity were significantly improved by $PW_4Mo_8/g-C_3N_4$ compared with $PW_{12}/g-C_3N_4$, PW_4Mo_8 , and PW_{12} in the oxidation of sulfides and alcohols. This s-scheme photocatalyst has many advantages such as high activity, high specific surface area, strong oxidizing ability, non-toxicity, and high recyclability.

2. Experimental

2.1. Materials and Physical Techniques

Chemicals used in this work were purchased from Fluka and Merk chemical companies and used without purification. FT-IR spectra were obtained over the region 400-4000 cm⁻¹ with NICOLET IR100 FT-IR with spectroscopic grade KBr. The phase purity and crystalline structure of samples were analyzed by using Philips X-pert X-ray diffractometer using Cu K α radiation ($\alpha = 0.154056$ Å). For specific surface areas, BET (Micromeritics Instrument Corporation TriStar II) was used. The field emission scanning electron microscopy (FESEM) analysis was carried out using a Philips

XL-300. The UV/Vis diffusive reflectance (UV/Vis DRS) was obtained using Thermo Scientific Evolution 300/600 UV-Visible spectrophotometer (USA) spectrophotometer. The visible illumination was provided by a 400 W lamp (high-pressure mercury-vapor lamp and λ =546.8 nm.

2.2. Preparation and characterization of the photocatalyst

The bulk graphitic carbon nitride (g-C₃N₄) was synthesized by thermal condensation of melamine following a previously published method [62]. HPAs nanoparticles were prepared according to reported reference [50]. For the synthesis of PW_4Mo_8/g -C₃N₄, the g-C₃N₄ (0.5 g) was taken in ethanol (30 ml) and sonicated for 2 h to make the thick slurry. H₃PMo₈W₄O₄₀ (0.8 g) was added to the slurry and then sealed and stirred for 20 hours. Afterward, the cap was removed and the solid phase was filtered. Subsequently, it was dried at 75 °C. The steps of photocatalyst preparation are illustrated in Scheme 1.



Scheme 1. Schematic representation of the synthesis of magnetic PW₄Mo₈/g-C₃N₄.

2.3. General procedure for the oxidation reaction of sulfides and alcohols in the presence of $PW_4Mo_8/g-C_3N_4$ as photocatalyst

A mixture of sulfide or alcohol (1 mmol), 0.5 mL of H_2O_2 33%, 10 mL of ethanol as solvent, and 0.005 g of PW_4Mo_8/g -C₃N₄ as photocatalyst was added. The reaction mixture was then stirred under visible light irradiation for an appropriate time (Table 2, 3) until the completion of the reaction was achieved as monitored by TLC. After the photocatalytic reaction, the suspension was centrifuged at 5000 rpm for 10 min and the supernatant was analyzed by gas chromatography (GCYonglin 6100; BP-5; 30m×0.25×mm×0.25µm).

3. Results and discussion

3.1 PW₄Mo₈/g-C₃N₄ as photocatalyst for oxidation of sulfides to the sulfoxides:

Preliminary, the catalyst effect on the oxidation of thioanisole (1a) as the model substrate was studied. Various conditions on the yield were investigated using visible light irradiation, reaction temperature, catalyst loading, various catalysts, oxidants, and solvents. (Table 1)

$S \longrightarrow \frac{Catalyst, visible light, oxidant}{Solvent, T °C, } \bigcup_{lb} O$							
Entry	Catalyst	Catalyst	Solvent	oxidant	Time	T∘C	Yield ^b
		amount (g)			(mın)		(%)
1	None	-	EtOH	H_2O_2	110	45-55	-
2	$g-C_3N_4$	0.002	EtOH	H_2O_2	110	45-55	-
3	$PW_4Mo_8/g-C_3N_4$	0.005	EtOH	H_2O_2	110	25-35	45
4	$PW_4Mo_8/g\text{-}C_3N_4$	0.005	EtOH	H_2O_2	110	45-55	Trace
	(Without light)						
5	PW_{12}	0.003	EtOH	H_2O_2	110	45-55	75
6	PW ₄ Mo ₈	0.003	EtOH	H_2O_2	110	45-55	78

Table 1. Optimization for the oxidative reaction 1a with oxidant^a

7	PW ₁₂ @g-C ₃ N ₄	0.005	EtOH	H_2O_2	110	45-55	83
8	$PW_8Mo_4/g-C_3N_4$	0.005	EtOH	H_2O_2	110	45-55	80
9	PW_6Mo_6/g - C_3N_4	0.005	EtOH	$\mathrm{H}_{2}\mathrm{O}_{2}$	110	45-55	88
10	$PW_4Mo_8/g-C_3N_4$	0.005	EtOH	H_2O_2	110	45-55	91
11	$PW_2Mo_{10}/g-C_3N_4$	0.005	EtOH	H_2O_2	110	45-55	82
12	PMo_{12}/g - C_3N_4	0.005	EtOH	H_2O_2	110	45-55	74
13	$PW_4Mo_8/g-C_3N_4$	0.005	EtOH	O_2	110	45-55	58
14	$PW_4Mo_8/g\text{-}C_3N_4$	0.005	EtOH	air	110	45-55	27
15	$PW_4Mo_8/g-C_3N_4$	0.003	EtOH	H_2O_2	110	45-55	85
16	$PW_4Mo_8/g\text{-}C_3N_4$	0.007	EtOH	H_2O_2	110	45-55	90
17	$PW_4Mo_8/g\text{-}C_3N_4$	0.005	DMSO	H_2O_2	110	45-55	25
18	$PW_4Mo_8/g-C_3N_4$	0.005	CH ₃ CN	H_2O_2	110	45-55	27
19	$PW_4Mo_8/g\text{-}C_3N_4$	0.005	DMF	H_2O_2	110	45-55	55
20	$PW_4Mo_8/g-C_3N_4$	0.005	H_2O	H ₂ O ₂	110	45-55	58

^{*a*}Reaction conditions: 1 mmol of 1a, 3 mmol of H₂O₂, catalyst. ^{*b*}Isolated yield.

It was found that the reaction did not proceed without a heteropolyacid as a catalyst and no activity was observed in the presence of bare g-C₃N₄ (entries 1 and 2). Then, the effect of light irradiation on the reaction was investigated and it was found that the reaction worked out best under visible light irradiation. Also, in the absence of light, only trace amounts of the product were formed and the starting materials remained almost intact (entry 4). Generally, the activity of heteropolyacid/g-C₃N₄ in catalytic conditions versus the oxidation was higher than that of the pristine heteropolyacid (entry 4 and 5) and the catalytic activity of PW₄Mo₈/g-C₃N₄ was higher than PW₁₂@g-C₃N₄, PW₈Mo₄/g-C₃N₄, PW₆Mo₆/g-C₃N₄, PW₂Mo₁₀/g-C₃N₄, and PMo₁₂/g-C₃N₄ (entries 6-11). Also, the use of H₂O₂ as an oxidant gave higher yields than O₂ and air (entry 12, 13). Reducing the amount of catalyst leads to a decrease in yield (entry 14). The reaction produces the best yield under visible-light irradiation, using 0.005 g of catalyst and H_2O_2 as the oxidant in EtOH. To explore the scope, the optimized conditions are extended to a variety of sulfides and alcohols. (Table 2, 3).

	0	PW_4Mo_8/gC_3N_4 , hv	0	
	R_1 R_2 R_2 R_1 R_2 R_2 R_2	EtOH, 25-35 ⁰ C H ₂ O ₂ (33%)	R ₁ R ₂ 1b-11b	
Entry	Substrate 1a-11a	Product 1b-11b	Time (min)	Yield ^b (%)
1	⟨s		110	91
2	Br	Br	75	88
3			115	87
4	NO ₂		105	80
5	Q_s_C		80	93
6			140	88
7	Br		150	68
8			140	73
9	$\langle \rangle$	\sum s=0	60	85
10			85	91
11	~~s~~~		110	90

Table 2. Oxidation of sulfides to the sulfoxides catalyzed by PW₄Mo₈/g-C₃N₄

^{*a*}All reactions were carried out using **1-11** (1 mmol) and 0.005 gr of catalyst in 10 mL of ethanol under visible light irradiation. ^{*b*}Isolated yields.

	ОН	PW_4Mo_8/gC_3N_4 , hv		
	R ₁ CH ₂ R ₁ : CH ₃ , Ph	EtOH, 45-55 0 C R ₁ R ₂ H ₂ O ₂ (33%) R ₂ : H, CH ₃ , Ph, C ₆ H ₁₃		
Entry	Substrate 1c-8c	Product 1d-8d	Time (min)	Yield ^b (%)
1	ОН		75	88
2	CI		100	90
3	Ме	Me	120	80
4	мео	MeO	140	78
5	OH		160	83
6	OH		115	85
7	ОН		150	62
8	OH V NO ₂		60	87

Table 3. Oxidation of alcohols with hydrogen peroxide catalyzed by PW₄Mo₈/g-C₃N₄^a

^aAll reactions were carried out using 1-8 (1 mmol) and 0.005 gr of catalyst in 10 mL of ethanol under visible light irradiation.

^bIsolated yields.

3.2 Possible mechanism for the photocatalytic oxidations

The accepted mechanism for the oxidation of alcohols and sulfides in the presence of PW_4Mo_8/g -C₃N₄ and H₂O₂ under visible light is described in Scheme 2.



Scheme 2. The photocatalytic mechanism diagram of PW₄Mo₈/g-C₃N₄ under visible light irradiation.

3.2.1 Scavengers for determination of active species

To understand the key reactive species in the sunlight driven sulfides and alcohols oxidation process by $PW_4Mo_8/g-C_3N_4$, a series of control reactions were performed by adding different radical scavengers into the system. In this study, 1 mmol of KI, AgNO₃, and t-BuOH was added into the reaction mixture for h+, e- and ·OH trapping, respectively. As illustrated in Figure 1. The addition of KI significantly suppressed the efficiency of the oxidation reaction and a relatively smaller effect was observed when AgNO₃, t-BuOH were added to the reaction system. These observations confirmed that photogenerated holes, e⁻, and ·OH were the main oxidative species in the oxidation of alcohols and sulfides in the presence of $PW_4Mo_8/g-C_3N_4$ as a photocatalyst.



Figure 1. Effects of radical scavengers on the oxidation yields of Thioanisole and 1-phenylethanol in the presence of PW₄Mo₈/g-C₃N₄.

3.2.2 Possible oxidation mechanism

Combining our experiment results with related studies [63-67], a postulated mechanism for the oxidation of alcohols and sulfides in the presence of $PW_4Mo_8/g-C_3N_4$ and H_2O_2 under visible light is described in Scheme 3. At first, under the irradiation, the electrons (e⁻) are excited from the VB to the CB of the catalyst leaving behind (h⁺). The electrons are very active, so, can be easily trapped and transferred to the H_2O_2 promoting the (\neg OH) and (\cdot OH) formation. Then alcohols undergo a deprotonation reaction with \neg OH to produce alkoxide anions. In the oxidative reaction, the alkoxide anions react with the positive holes (h⁺) and produce alkoxide radicals. It is observed that the dehydrogenation reaction with (\cdot OH) produced the carbonyl compounds. Also, the oxidation mechanism of sulfides is proposed in Scheme 3.



Scheme 3. Possible passway for oxidation of alcohols and sulfides with hydrogen peroxide catalyzed by PW_4Mo_8/g -C₃N

3.3. Characterization of the catalyst

The Fourier transform infrared (FT-IR) spectroscopy of (a) the PW₄Mo₈ and (b) PW₄Mo₈/g- C_3N_4 were also investigated in the range of 500–4000 cm⁻¹. The chief peaks of PW₄Mo₈/g- C_3N_4 located at 1048 and 1020 cm⁻¹ (v P-O), 930–945 cm⁻¹ (v metal=O), 850–890 cm⁻¹ (v metal-O-metal) and 769 cm⁻¹ (v metal-O-metal) were observed (Figure 2a). For PW₄Mo₈/g- C_3N_4 , the peaks between 3100 and 3300 cm⁻¹ are assigned to N-H and OH stretching vibrations. As well as, the bands at 1150-1750 cm⁻¹ regions are attributed to aromatic C-N heterocycles. The intensity of the specific bands of H₃PW₄Mo₈O₄₀ is low, due to the presence of a small amount of HPA on the g- C_3N_4 (Figure 2b) [68].



Figure 2. The FT-IR spectra of (a) the PW_4Mo_8 and (b) $PW_4Mo_8/g-C_3N_4$.

The XRD measurements were implemented to investigate the presence as well as the crystallinity degree and purity of g-C₃N₄, PW₄Mo₈, and PW₄Mo₈/g-C₃N₄ catalysts (Figure 3). The XRD pattern of g-C₃N₄ showed diffraction peaks at $2\theta = 13.1$ and 27.5 correspondings to the reflection planes (100) and (002), respectively (JCPDS No. 87-1526) [69, 70]. The intensity of the (100) plane is quite good which confirms the presence of a graphite-like structure. The sample of PW₄Mo₈ exhibits peaks at 7°~10°, 16°~23°, 25°~31°, and 36°~43° corresponding to the peaks of the Keggin structure, which demonstrated that heteropoly acid with Keggin structure had been prepared [71]. Whole these diffraction peaks have remained in the XRD patterns of PW₄Mo₈/g-C₃N₄ compound but with reduced intensity, which can result from the decrease crystallite size. The XRD pattern of both the g-C₃N₄ and PMo₈W₄/g-C₃N₄ showed a strong diffraction peak at 2 θ =27.5°, which indicated the characteristic interlayer stacking of aromatic systems. Thus the XRD pattern of the PW₄Mo₈/g-C₃N₄ exhibits the typical Keggin-type diffraction peaks and g-C₃N₄ diffraction peaks which indicated that PW₄Mo₈ was loaded on g-C₃N₄ successfully.



Figure 3. XRD of g- C_3N_4 , PW_4Mo_8 , and PW_4Mo_8/g - C_3N_4 .

The SEM images of $g-C_3N_4$ support and $PW_4Mo_8/g-C_3N_4$ catalyst are reported in Figure 4. As seen in Fig. 4b, the $g-C_3N_4$ were covered by some crystals that indicate an acid-base reaction between PW_4Mo_8 and the NH/NH₂ groups present in the $g-C_3N_4$ materials has occurred.



Figure 4. SEM image of (a) g-C₃N₄ and (b) PW₄Mo₈/g-C₃N₄

The DRS spectra were recorded to study the optical properties of the PW_4Mo_8 and PW_4Mo_8/g -C₃N₄ (Figure 5). The band gap energy of PW_4Mo_8 and PW_4Mo_8/g -C₃N₄ was estimated to be 3.53 and 2.54 eV respectively. The reduced band gap energy of PW_4Mo_8/g -C₃N₄ could lead to better

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absorption of light in the visible region favoring more e⁻h⁺ pair formation, thus probably resulting in improved photoactivity.



Figure 5. a) Diffuse reflectance spectra and band gaps of (a) PW₄Mo₈ and (b) PW₄Mo₈/g-C₃N₄.

To investigate the band-edge potentials of g-C₃N₄ and PW₄Mo₈ photocatalyst, Mott-Schottky plots were used at frequency of 500 Hz (Fig. 6). In Figure 6, which illustrates the plots, the positive slope of the curves indicates that both g-C₃N₄ and PW₄Mo₈ have typical n-type semiconductor nature [72]. The flat band potentials (E_{FB}) of the samples are estimated to be – 1.3 and – 1.0 V (vs Ag/AgCl, pH=7), based on the tangent of their Mott-Schottky curves. As is well known, the conduction band edge (E_{CB}) is about 0.1– 0.2 eV below the E_{FB} for an n-type semiconductor [73]. Thus, by considering it as 0.2, the CB edges for g-C₃N₄ and PW₄Mo₈ are calculated as – 1.5 eV and – 1.2 eV. The VB positions of g-C₃N₄ and PW₄Mo₈ are calculated to be 1.35 and 2.33 eV, respectively. Based on the results from Mott-Schottky plots, the conduction band edge of g-C₃N₄ is clearly more negative than the conduction band of PW₄Mo₈, whereas the valance band of g-C₃N₄ is less positive than the VB of PW₄Mo₈. A more negative E_{VB} suggests a higher photoelectrochemical and photocatalytic oxidative activity [74]. The diagrams of the band energy of the g-C₃N₄ and PW₄Mo₈ are presented in Scheme 2.



Figure 5. Mott - Schottky plots of g-C₃N₄ and PW₄Mo₈ at 500 Hz.

To describe the textural properties of the catalyst, the nitrogen adsorption-desorption isotherm was measured and the results are presented in Figure 7. In general, the sample had an IV isotherm with a type of H3 hysteresis loop. The hysteresis loops at a relative pressure (P/P0) range of 0.4-0.95 indicated the mesoporous structure of $PW_4Mo_8/g-C_3N_4$. Pristine g-C₃N₄ had a low BET surface area of 10.1 m²/g, which was consistent with the reported value. [75, 76] After g-C₃N₄ was decorated with PW₄Mo₈, the specific surface area increased to 25.22 m²/g. Accordingly, the specific surface area was increased. The improved textural property of g-C₃N₄ can be ascribed to the hydrothermal treatment as the specific surface area of POMs is generally as low as g-C₃N₄.



Figure 7. N₂ sorption isotherms of photocatalyst.

Conclusion

In summary, graphitic carbon nitride (g-C₃N₄) is a promising visible-light photocatalyst due to its unique electronic structure. The visible-light photocatalytic efficiency of g-C₃N₄ is relatively low and far from the requirements of practical applications. Therefore, it has been decorated with molybdenum-substituted tungstophosphoric acid (PW₄Mo₈/g-C₃N₄) to develop a higher performance photocatalyst, and then it has been employed as an effective photocatalyst in the presence of visible light and H₂O₂ to effect the oxidation of alcohols and sulfides. In the present work, we have examined five different H₃PW_{12-y}Mo_yO₄₀/g-C₃N₄ photocatalysts in our reactions among which the PW₄Mo₈/g-C₃N₄ is found the best. We have used the Keggin/g-C₃N₄ (previously reported by us) in this work for the purpose of comparison with (PW₄Mo₈/g-C₃N₄) to verify that (PW₄Mo₈/g-C₃N₄) was superior in terms of yields as well as reaction times. The catalyst is able to oxidize sulfides and alcohols with excellent yields, and without over-oxidation or the formation of other by-products.

Acknowledgements

The financial support of this work, by Kosar University of Bojnord is gratefully

acknowledged.

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g-C₃N4/H₃PW₄Mo₈O₄₀ S-scheme photocatalyst with enhanced photocatalytic oxidation of alcohols and sulfides

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graphitic carbon nitride $(g-C_3N_4)$ decorated with molybdenum-substituted tungstophosphoric acid $(H_3PW_4Mo_8O_{40})$ as a novel photocatalyst (and used to catalyze the oxidation of alcohols and sulfides. Increasing of the reaction rate in the photo-assisted catalytic reaction under visible light illumination can be due to the redox and the acidity properties of PW₄Mo_8/g-C_3N_4.



Highlights

- ✓ Designing a new set of HPAs as photocatalyst under visible-light.
- Proving the promising role of Mo cations in selective photocatalytic oxidation of alcohols and sulfides.
- ✓ The g-C₃N₄ with electronic structural property as visible-light active photocatalyst