1. Introduction

Within the background of rapid economic development, environmental governance is gradually being focused upon. Semiconductor mediated photocatalysis has attracted considerable attention because it provides highly efficient and energy saving pathway for disposing wastewater and water purification.

Cadmium sulphide (CdS) is an essential II–VI group semiconductor, which has been studied extensively due to its narrow band gap ($E_g = 2.42 \text{ eV}$) at 300 K, high absorption coefficient > $10^4$ and size dependent electronic and optical properties. Therefore, CdS is an attractive candidate as a photocatalyst, which can efficiently absorb visible light. However, its activity and stability far from satisfying the demand of researchers because of rapid charge recombination and photo-corrosion, which limit its large scale applications. Also, it is desirable that the photocatalyst material should be easily separable from the reaction system after the degradation of the target pollutant. There are many ways to solve the problems to enhance the photocatalytic activity of CdS, such as the deposition of noble metallic compounds, the preparation CdS quantum dots and the formation of heterojunction semiconductors. A nanocomposite heterostructured system utilizing two semiconductor materials with different band gaps is a novel strategy used to improve the photocatalytic activity. Simultaneously, considering recycling is a necessary factor for an outstanding photocatalyst, we adopted a magnetic material to form a Type II heterojunction with CdS. Recently, spinel cobalt ferrite (CoFe$_2$O$_4$) nanoparticles have attracted a great deal of attention due to their chemical stability, mechanical hardness, magnetocrystalline anisotropy, high coercivity and moderate saturation magnetization. The large saturation magnetization of novel materials based on CoFe$_2$O$_4$ allows fast and effective separation from an aqueous solution using an external magnet, so CoFe$_2$O$_4$ has been widely applied in the photocatalysis field. For example, Wetchakun synthesized a CoFe$_2$O$_4$/CeO$_2$ nanocomposite material by coupling a precipitation method with a hydrothermal method, which was used as a magnetic photocatalyst for degrading organic pollutants. Gupta combined CoFe$_2$O$_4$ with TiO$_2$ using a hydrothermal method to degrade chlorpyrifos. Moreover, other composite photocatalysts have also been reported, such as CoFe$_2$O$_4$/graphene, CoFe$_2$O$_4$/ZnO, CoFe$_2$O$_4$/Ag$_2$PO$_4$ (ref. 19) and so on. Moreover, supports are always used to improve the performance of the photocatalyst. Graphene oxide (GO) or reduced-GO (rGO), a two-dimensional (2D) monolayer of graphitic sp$^2$ hybridized carbon, has been reported as effective for the transfer of photoelectrons due to its high electron mobility, large specific surface area and excellent thermal conductivity in semiconductor heterojunction materials to enhance the photocatalytic performance, such as AgBr/ZnO/rGO, Bi$_2$S$_3$/TiO$_2$/rGO, [C$_{16}$H$_{31}$CH$_2$]$_n$W$_4$O$_{12}/g$-C$_3$N$_4$/rGO, Ni@graphene-Cu, etc., so the fabrication of graphene-based photocatalysts has been deemed to be one of the most feasible strategies used to optimize the photocatalytic performance.

On account of the above considerations, we now reported the CdS/CoFe$_2$O$_4$/rGO photocatalyst prepared via a hydrothermal method. Tetracycline was chosen as a target pollutant to detect
the photocatalytic performance. The results exhibited that both the heterojunction of CdS/CoFe₂O₄ and rGO played important roles in the photocatalytic activity. This study provides a promising candidate for the efficient removal of tetracycline using an environmentally friendly and economical approach.

2. Experimental

2.1 Chemicals and reagents

Iron(III) nitrate nonahydrate (Fe(NO₃)₃·9H₂O, AR), cobalt nitrate hexahydrate (Co(NO₃)₂·6H₂O, AR) and sodium sulfide (Na₂S, AR) were all purchased from Shanghai Chemical Reagent Co., Ltd. Polyvinylpyrrolidone (PVP, AR), ethanol (C₂H₅OH, 95%) potassium permanganate (KMnO₄, AR), graphite power, sodium nitrate (NaNO₃, AR), hydrochloric acid (HCl, AR), sulfuric acid (H₂SO₄, AR) and ethanol (C₂H₅OH, 95%) were all supplied from Sinopharm Chemical Reagent Co., Ltd. Cadmium chloride hemi(pentahydrate) (CdCl₂·2.5H₂O, 98%), ethylene glycol (98%, AR), hydrogen peroxide (H₂O₂, 30%), sodium hydroxide (NaOH, 97%) and L-cysteine (C₃H₇NO₂S, AR) were all purchased from Aladdin Chemistry Co., Ltd. Tetracycline was analytically pure and used without any further purification. Distilled water was used in all our experiments.

2.2 Synthesis

2.2.1 Preparation of GO. Graphene oxide (GO) was synthesized using the modified Hummer’s method, through the natural oxidation of graphite powder. Firstly, 1 g of graphite powder, 2.5 g of NaNO₃ and 30 mL of concentrated H₂SO₄ were added to a 250 mL three-necked flask, then placed in an ice bath and stirred to obtain a homogeneous suspension. Secondly, 4 g of KMnO₄ was added to the suspension and stirred for 30 min under a nitrogen atomization. Subsequently, the solution was transferred into a Teflon-lined stainless steel autoclave for hydrothermal treatment at 240 °C for 24 h. After the autoclave was allowed to cool to room temperature naturally, the as-formed precipitate was collected by centrifugation, washed several times with water and ethanol, and dried at 60 °C for 12 h.

2.2.2 Preparation of CoFe₂O₄. Pure CoFe₂O₄ was synthesized using a traditional hydrothermal method. Briefly, 4 mM Fe(NO₃)₃·9H₂O and 2 mM Co(NO₃)₂·6H₂O were dissolved in 40 mL of ethylene glycol, followed by the addition of 15 mM PVP under mechanically stirring for 30 min to obtain a clear solution. Then, the solution was transferred into a Teflon-lined stainless steel autoclave for hydrothermal treatment at 240 °C for 24 h. After the autoclave was allowed to cool to room temperature naturally, the as-formed precipitate was collected by centrifugation, washed several times with water and ethanol, and dried at 60 °C for 12 h.

2.2.3 Preparation of CdS/CoFe₂O₄/rGO. CdS/CoFe₂O₄/rGO was synthesized via a simple hydrothermal method. Briefly, 0.1833 g of CdCl₂·2.5H₂O and 0.1756 g of L-cysteine were dissolved together in 40 mL of deionized water and stirred for 30 min. Then, the pH was adjusted to pH = 7.0 using 0.1 mol L⁻¹ NaOH, then 0.05 g of CoFe₂O₄ and 0.05 g of GO were added to the above suspension and allowed to dissolve for 30 min. Then, 0.045 g of Na₂S·9H₂O was added to the above suspension and stirred for 30 min under a nitrogen atmosphere. Subsequently, the solution was transferred into a Teflon-lined stainless steel autoclave for hydrothermal treatment at 180 °C for 2 h. The suspension was separated using an external magnet and the precipitate was washed with ethanol and water, and dried in vacuo at 60 °C for 24 h. The preparation process of CdS/CoFe₂O₄/rGO is shown in Scheme 1.

2.3 Characterization

In this work, X-ray diffraction (XRD) patterns were obtained using a D/max-X-ray diffractometer (Rigaku, Japan), which was equipped with Ni-filtered Cu Kα radiation (40 kV, 30 mA) to characterize the crystal structure. The 2θ scanning angle range was 10–80° at a scanning rate of 5° min⁻¹. Transmission electron microscopy (TEM) images were examined on an F20 S-
TWIN electron microscope (Tecnai G2, FEI Co.). The SEM images were collected with a S-4800 scanning electron microscopy (HTAUCHI, Japan). The UV-vis diffuse reflectance spectra (UV-vis DRS) of the photocatalyst power was obtained for the dry-pressed disk samples using a Specord 2450 spectrophotometer (Shimazu, Japan) equipped with an integrated sphere accessory for diffuse reflectance spectra using BaSO4 as the reference sample. Raman experiments were performed using a DXR spectrometer with a 532 nm laser and the measurements were made in a back scattering geometry. The room-temperature photoluminescence (PL) spectra of the samples were investigated utilizing a Cary Eclipse Spectrophotometer (VARIAN, USA) equipped with a xenon (Xe) lamp. The magnetic measurements were carried out using a vibrating sample magnetometer (VSM) (HH-15, Jiangsu University). The photocurrent and electrochemical impedance spectroscopy (EIS) measurements were conducted on a CHI852C electrochemical workstation and CHI760E workstation, respectively. The ESR signals of the radicals spin-trapped by the spin-trapping reagent 5,5-dimethyl-1-pyrroline N-oxide (DMPO) were investigated on a Bruker EPR CHI760E workstation, respectively. The ESR signals of the radicals spin-trapped by the spin-trapping reagent 5,5-dimethyl-1-pyrroline N-oxide (DMPO) were investigated on a Bruker EPR

\[
\eta = \frac{C_0 - C_i}{C_0}
\]

where \(\eta\) is the Dr; \(C_0\) is solution concentration at the end of the dark reaction; \(C_i\) is the absorption of the reaction solution.

2.4 Activity test

The photocatalytic activity test of the as-prepared photocatalyst was investigated by degrading tetracycline with an initial concentration of 20 mg L\(^{-1}\) under visible light irradiation (a 350 W Xe lamp with a 420 nm cut-off filter). In brief, 0.1 g catalyst was dispersed in 100 mL of tetracycline aqueous solution. Before irradiation, the photocatalyst solution was mechanically stirred for 30 min to establish an absorption-desorption equilibrium between tetracycline and the photocatalyst. At given time intervals, small aliquots were sampled and centrifuged twice at 10 000 rpm for 3 min to remove the photocatalyst nanoparticles and analyzed by recording the variation in the absorption band (358 nm) in the UV-vis spectrum of tetracycline using a UV-vis spectrophotometer. The photocatalytic degradation rate (Dr) was calculated as follows:

The photocatalytic activity test of the as-prepared photocatalyst was investigated by degrading tetracycline with an initial concentration of 20 mg L\(^{-1}\) under visible light irradiation (a 350 W Xe lamp with a 420 nm cut-off filter). In brief, 0.1 g catalyst was dispersed in 100 mL of tetracycline aqueous solution. Before irradiation, the photocatalyst solution was mechanically stirred for 30 min to establish an absorption-desorption equilibrium between tetracycline and the photocatalyst. At given time intervals, small aliquots were sampled and centrifuged twice at 10 000 rpm for 3 min to remove the photocatalyst nanoparticles and analyzed by recording the variation in the absorption band (358 nm) in the UV-vis spectrum of tetracycline using a UV-vis spectrophotometer. The photocatalytic degradation rate (Dr) was calculated as follows:

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2.5 Photoelectrochemical (PEC) measurements

The photocurrent was measured on an CHI852C electrochemical workstation using a standard three-electrode system. The IPCE measurements were carried out in a three-electrode. The CdS, CdS/CoFe2O4 and CdS/CoFe2O4/rGO samples on FTO substrates were used as working electrodes, and Ag/AgCl (saturated KCl) and platinum wire as the reference and counter electrodes, respectively. The working electrode was in the range of 1 cm\(^2\) with 0.5 M NaSO4 solution as a supporting electrolyte with 0.5 V versus SCE applied on the photoanode for the photocurrent test on the on-light conditions. EIS measurements were carried out in a three-electrode electrochemical cell on a CHI760E electrochemical workstation. A 0.1 M KCl solution containing 5 mM Fe(CN)\(_6^{3-}/4^-\) was used as the electrolyte.

3. Results and discussion

3.1 XRD analysis

The XRD patterns of the CdS (a), CoFe2O4 (b) and CdS/CoFe2O4/rGO (c) samples are displayed in Fig. 1. The diffraction peaks of pure CdS located at 24.8°, 26.5°, 28.1°, 43.6°, 47.7° and 52.7° corresponding to (1 0 0), (0 0 2), (1 0 1), (1 1 0), (1 0 3) and (2 0 1) can be indexed to CdS with a greenockite structure (JCPDS No. 41-1049). Fig. 1b at 2θ of 18.2°, 30.1°, 35.4°, 43.0°, 56.9° and 62.5° are respectively assigned to the (1 1 1), (2 2 0), (3 1 1), (4 0 0), (5 1 1) and (4 4 0) diffraction planes of CoFe2O4 cobalt iron oxide structure (JCPDS No. 22-1086). The sharp and intense peaks illustrate that the samples are well-crystallized. Obviously, the 35.4°, 56.9° and 62.5° diffraction peaks of CoFe2O4 in Fig. 1c become low and even disappear, which is attributed to the CdS deposition on the surface of CoFe2O4 and the diffraction peak of CdS is very distinct, which also reveals the successful formation of an heterojunction between CdS and CoFe2O4. The inset is the XRD pattern of GO, whose diffraction peak is located at 10.9°, but the typical diffraction peak of GO in Fig. 1c almost disappears after the hydrothermal reaction, which was attributed to the content of GO being very low.

3.2 TEM images

Fig. 2 shows the TEM images of the CdS nanoparticles, CoFe2O4, GO and CdS/CoFe2O4/rGO, respectively. From Fig. 2a, the CdS nanoparticles are seriously aggregated; the main aggregation peaks illustrate that the samples are well-crystallized. Obviously, the 35.4°, 56.9° and 62.5° diffraction peaks of CoFe2O4 in Fig. 1c become low and even disappear, which is attributed to the CdS deposition on the surface of CoFe2O4 and the diffraction peak of CdS is very distinct, which also reveals the successful formation of an heterojunction between CdS and CoFe2O4. The inset is the XRD pattern of GO, whose diffraction peak is located at 10.9°, but the typical diffraction peak of GO in Fig. 1c almost disappears after the hydrothermal reaction, which was attributed to the content of GO being very low.

![Fig. 1](image_url)

**Fig. 1** The XRD patterns obtained for CdS (a), CoFe2O4 (b), CdS/CoFe2O4/rGO (c).
agreement with those (0.301 and 0.235 nm) of the (2 2 0) and (3 1 1) crystal planes of the standard CoFe$_2$O$_4$ sample, indicating the CoFe$_2$O$_4$ sample possessed good crystallinity. The observation of multiple bright electron diffraction rings in the SAED patterns (inset of Fig. 2b). Fig. 2c shows that rGO exhibits a typical wrinkled texture and most of the sheets resembled slightly crumpled paper. As shown in Fig. 2d, a relatively uniform distribution of the CdS and CoFe$_2$O$_4$ nanoparticles on the rGO sheets was obtained by the introduction rGO. This may be because an interfacial electron field was established on the interface between the rGO and the CdS and CoFe$_2$O$_4$ nanoparticles.

### 3.3 SEM images

Fig. 3a–c show the different magnification SEM images of CdS/CoFe$_2$O$_4$/rGO. From Fig. 3a, we can clearly see that the surface of the CdS/CoFe$_2$O$_4$/rGO was very rough and the CdS nanoparticles are different in shape, the CdS was homogeneously distributed on the CoFe$_2$O$_4$ and rGO, and the construction of the CdS and CoFe$_2$O$_4$ heterojunction. In Fig. 3b is the magnified image of CoFe$_2$O$_4$ with CdS, which exhibits spherical-like nanoparticles. We intercepted a portion from Fig. 3c to complete the EDX measurement. The corresponding EDX measurement further confirms the existence of the elements Co, Fe, O, Cd, S, C and Au. Quantitative analysis reveals that the atomic ratio of Co and Fe in the hybrid was nearly equal to 1 : 2, which is consistent with the stoichiometric composition of CoFe$_2$O$_4$. Note that the occurrence of the element Au was due to the metal spraying step performed before the SEM measurements.

### 3.4 UV-vis DRS analysis

Fig. 4 shows the UV-vis diffuse reflectance spectra of CdS, CoFe$_2$O$_4$ and the CdS/CoFe$_2$O$_4$/rGO photocatalyst. For pure CdS, a strong absorption located at ca. 557 nm originating from the intrinsic band-edge absorption of the CdS nanoparticles can be seen. Pure CoFe$_2$O$_4$ has a remarkable absorption in the range of 200–800 nm, which may be due to its black color. In contrast, from the absorptions of pure CdS, CoFe$_2$O$_4$ and the CdS/CoFe$_2$O$_4$/rGO nanocomposite, it can be seen that the absorption at all wavelengths was much stronger in the CdS/CoFe$_2$O$_4$/rGO nanocomposite due to the presence of rGO and the formation of the heterojunction between CdS and CoFe$_2$O$_4$. This increase in the absorbance in the visible light region is in accordance with the color change of the photocatalyst from golden yellow to
deep brown and should have implications in the photocatalytic capability of the composite. The band gap of the samples can be calculated as follows:

$$\alpha(h\nu) = A(\nu - E_g)^n$$

(2)

where $\alpha$, $r$, $A$, $E_g$ and $n$ are the absorption coefficient, light frequency, constant, band gap energy and $n = 1$ for a direct-band-gap semiconductor and $n = 4$ for an indirect-band-gap semiconductor. Pristine CdS was calculated from the optical absorption $(\alpha h\nu)^{1/2}$ versus photon energy plot in accordance with previous studies where CdS has been considered as a direct band gap material. So from Fig. 4, the estimated band-gap values are 2.23 eV and 1.58 eV corresponding to pure CdS and CdS/CoFe$_2$O$_4$/rGO, respectively. This may be ascribed to the acossentional sub-band gap energy levels induced by the serious interface and surface defects in the agglomerated nanoparticles.

3.5 Raman spectra analysis

In order to study the bonding properties and defects of graphitic materials, GO and CdS/CoFe$_2$O$_4$/rGO were analyzed by Raman spectroscopy. The sp$^3$ structural defects in carbon and the stretching of the C–C bonds in the graphitic materials seen from D band are ascribed to the G band, which is the typical in-plane vibration of sp$^3$ bonded carbons. Fig. 5 shows the spectra of GO and CdS/CoFe$_2$O$_4$/rGO. The Raman spectra shown in Fig. 5 reveals the characteristic D and G bands observed at 1343 and 1589 cm$^{-1}$ found in GO, respectively. However, the G bands of the as-prepared CdS/CoFe$_2$O$_4$/rGO are shifted to the lower frequency region when compared to the G bands of GO after the hydrothermal process. This phenomenon can be attributed to the recovery of the hexagonal network of carbon atoms with defects. The corresponding f(D)/f(G) ratio of GO and CdS/CoFe$_2$O$_4$/rGO in Fig. 5 were calculated to be 0.945 and 1.020, respectively. This increase may due to the high amount of defects after the reaction treatment or remnants of GO. We barely observed the characteristic Raman peak of CdS, which may due to the disturbing of the strong fluorescence properties in CdS.

3.6 Magnetic properties analysis

The magnetic properties of the as-prepared sample was measured by VSM at room temperature. Fig. 6 shows the hysteresis loops of CoFe$_2$O$_4$ and CdS/CoFe$_2$O$_4$/rGO. The VSM curve of CoFe$_2$O$_4$ shows that the saturation magnetization was 43.58 emu g$^{-1}$ at 15 026.85 Oe, which was higher than the photocatalyst. The size and shape anisotropy here play critical roles in determining the magnetic properties. With the assembly of the CdS nanoparticles on the surface of CoFe$_2$O$_4$, the saturation magnetization ($M_s$) of CdS/CoFe$_2$O$_4$/rGO decreased to 14.41 emu g$^{-1}$ at 15 094.50 Oe, such a decrease could be a result of the presence of the non-magnetic component. In addition, the remnant magnetization ($M_r$) of CdS/CoFe$_2$O$_4$/rGO was 623.9 Oe. This result shows that CdS/CoFe$_2$O$_4$/rGO displays the expectant magnetic performance and can be separated and easily recovered from the treated solutions after the liquid-phase photocatalytic degradation reaction (as shown in the photograph of Fig. 6), which can facilitate the practical running of an industrial wastewater treatment process.

3.7 Photocurrent response analysis

The photocurrent responses of CdS, CdS/CoFe$_2$O$_4$ and CdS/CoFe$_2$O$_4$/rGO shown in Fig. 7 were explored to investigate the electron generation and recombination behavior in the photocatalytic process. The CdS/CoFe$_2$O$_4$ composites exhibited a higher photocurrent response when compared to pure CdS, indicating that the synergistic effect between CdS and CoFe$_2$O$_4$ does indeed exist, so the separation of the photogenerated electrons and holes was increased. Obviously, the introduction of rGO forming the photocatalyst gave rise to the maximum photocurrent density in which the CdS/CoFe$_2$O$_4$/rGO was higher than that of pure CoFe$_2$O$_4$ and CdS/CoFe$_2$O$_4$ during the “on–off” irradiation cycles, resulting in the enhanced photocatalytic activity.
3.8 EIS analysis

Electrochemical impedance spectroscopy (EIS) analysis has also been used to examine the state of the charge carriers. As shown in Fig. 8, the diameter of the Nyquist plot obtained for CdS/CoFe2O4/rGO was the smallest at a high frequency. As is known to all, the high frequencies in the EIS spectra correspond to the charge transfer restrained at the contact interface both at the electrode and the electrolyte solution, and the charge transfer resistance can be directly observed by the semicircle radius. The smaller the semi arc in the EIS Nyquist plot denotes the lower recombination of the electron–hole pairs.\textsuperscript{41,42}

3.9 PL analysis

In order to examine the charge mobility, we adopted and analyzed the transient fluorescence (FL) of CdS and CdS/CoFe2O4/rGO excited at 337 nm (shown in Fig. 9B). The corresponding radiative lifetimes of the fitting decay curves obtained for CdS and CdS/CoFe2O4/rGO are 3.62 and 1.43 ns, respectively. The relatively shorter decay lifetime of the excited states reveals the faster interfacial electron transfer taking place in the semiconductors or the interfacial attachments and the improved separation of the electron–hole pairs.\textsuperscript{43} The quenched photoluminescence and the reduced decay lifetime further illuminate the greater separation of the photo-generated electrons and holes occurring at the interfaces of the compounds. CdS/CoFe2O4/rGO with the shorter decay time has an excellent capacity to utilize the charge carriers.

3.10 Photocatalytic activity

The photocatalytic activities of the as-prepared photocatalysts were evaluated by the degradation of 20 mg L\textsuperscript{-1} tetracycline under visible light irradiation. In order to discuss the effect different proportion of CoFe2O4 on the photocatalytic activity, from the degradation dynamics curves obtained for tetracycline over the CdS/CoFe2O4/rGO samples with different contents of CoFe2O4 shown in Fig. 10A, 0.05 g of CoFe2O4 in CdS/CoFe2O4/rGO exhibits the highest photocatalytic activity. The introduction of CoFe2O4 has a vital effect on the photocatalytic activity of the catalysts, which may be due to a majority of the electrons generated in the CdS can be transferred to the CoFe2O4 by the loaded sites under visible light irradiation; this additional route for electron transport can decrease the recombination of the electron–hole pairs. Moreover, Fig. 10B displays the photocatalytic capability of CdS, CoFe2O4, GO and CdS/CoFe2O4/rGO via the photodegradation of tetracycline. CdS/CoFe2O4/rGO reveals the best degradation rate of 56.3%, which indicates that CdS/CoFe2O4/rGO possesses the highest photocatalytic activity when compared to the other catalysts studied.

3.11 Stability

The stability of a photocatalyst is a necessary condition in practical application. To investigate the stability of the photocatalyst, recycling experiments for the photo-degradation of tetracycline were carried out and the results are shown in Fig. 11. It is clearly seen that CdS/CoFe2O4/rGO still maintains a high level of activity and does not exhibit an obviously decline after four cycles. CdS/CoFe2O4/rGO has satisfactory reusability during the photocatalytic reaction.
3.12 The mechanism of the pollutant photo-degradation process

The main active species during the photocatalysis process were determined using an electron spin resonance (ESR) spin-trap technique with DMPO, as shown in Fig. 12. Under visible light irradiation, the DMPO–·O$_2$/$\ce{C0}$ adduct over CdS/CoFe$_2$O$_4$/rGO was detected in a methanol dispersion (Fig. 12A). Six characteristic peaks existed in the spectra, which indicated that the photogenerated electrons in the conduction band of photocatalyst can combine with O$_2$ to produce ·O$_2$/$\ce{C0}$ radicals in the process of the photo-degradation reaction. For the DMPO–·OH signal, there are no or a little characteristic peaks in the spectra, suggesting nearly no ·OH was produced in the photocatalytic degradation reaction.

3.13 The proposed mechanisms of the CdS/CoFe$_2$O$_4$/rGO photocatalyst

For the purpose of gaining insight on how to improve the photocatalytic activity of the ternary CdS/CoFe$_2$O$_4$/rGO nanocomposites, the relative band edge of the CdS and CoFe$_2$O$_4$ semiconductors at the point of zero charge were calculated using the following empirical equations:

$$E_{CB} = X - E^* - 0.5E_g$$

$$E_{VB} = E_{CB} + E_g$$

where $E_{CB}$ and $E_{VB}$ are the conduction band (CB) and the valence band (VB) potentials, $E^*$ is the energy of the free electrons on the hydrogen scale (4.5 eV), $X$ is electronegativity of the semiconductor (the geometric mean of the electronegativity of the constituent atom) and $E_g$ is the band gap energy of the semiconductor. Accordingly, the $E_{VB}$ of CdS and CoFe$_2$O$_4$ were...
CdS and the h+ can oxidize the pollutant. Transferred to the sheets (9). Then, the negatively charged e− of CoFe2O4 (reaction (7)) and partial e− of Cds. Then, the negatively charged e− of CoFe2O4 (reaction (7)) and partial e− of Cds (h+) + CoFe2O4 (reaction (8)) when the e− are transferred from the ECB of Cds to the ECB of CoFe2O4 (38). The DMPO spin-trapping ESR spectra recorded with the Cds/CoFe2O4/rGO photocatalyst in (A) a methanol dispersion (for DMPO-superoxide radicals) and (B) an aqueous dispersion (for DMPO-hydroxyl radicals) under visible light irradiation.

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Fig. 12 The DMPO spin-trapping ESR spectra recorded with the Cds/CoFe2O4/rGO photocatalyst in (A) a methanol dispersion (for DMPO-superoxide radicals) and (B) an aqueous dispersion (for DMPO-hydroxyl radicals) under visible light irradiation.
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