

Review Article: Progressive Types of Fe₃O₄ Nanoparticles and Their Hybrids as Catalysts

Heshmatollah Alinezhad¹, Parvin Hajiabbas Tabar Amiri^{2,*}, Sahar Mohseni Tavakkoli,¹
Raed Muslim Muhiebes³, Yasser Fakri Mustafa⁴

¹Department of Organic Chemistry, Faculty of Chemistry, University of Mazandaran, Babolsar, Iran

²Department of Chemistry, Damghan University, Damghan, Semnan, Iran

³ Department of Biochemistry, College of Medicine, Misan University, Iraq

⁴ Department of Pharmaceutical Chemistry, College of Pharmacy, University of Mosul, Mosul, Iraq



Citation H. Alinezhad, P. Hajiabbasi*, S.M. Tavakkoli, R.M. Muhiebes, Y.F. Mustafa. **Progressive Types of Fe₃O₄ Nanoparticles and Their Hybrids as Catalysts.** *J. Chem. Rev.*, 2022, 4(4), 288-312.

doi <https://doi.org/10.22034/JCR.2022.325255.1137>



Article info:

Received: 18 January 2022

Accepted: 17 June 2022

Available Online: 22 June 2022

ID: JCR-2201-1137

Checked for Plagiarism: Yes

Language Editor:

Dr. Fatimah Ramezani

Peer Reviewers Approved by:

Dr. Hoda Hamidi

Editor who Approved Publication: Prof. Dr.

Ghasem Rezanejade Bardajee

Keywords:

Nanohybrid catalysts, Magnetic catalysts, Silica coating, Iron oxide nanoparticles

ABSTRACT

Here, we discuss about several important procedures of preparing Fe₃O₄ nanoparticles and their hybrids as magnetically and recoverable catalysts. Magnetic nanoparticles could be simply separated by applying the magnetic interaction using a magnetic field. As classified in this study, several groups were used to develop a sequence of magnetic nanoparticles as heterogeneous catalysts in organic transformations and other usages. The progressive preparation of supporting materials is emphasized in this article to develop the quality of magnetic nanoparticles.

List of content

1. Introduction
2. Various types of Fe₃O₄ nanohybrid catalysts
3. Nanohybrid Fe₃O₄ catalysts having silica as protective coating
 - 3.1. Nanohybrid Fe₃O₄ catalysts supported heteropolyacids
 - 3.2. Nanohybrid Fe₃O₄ catalysts supported ionic liquids
 - 3.3. Nanohybrid Fe₃O₄ catalysts supported metal bounds
 - 3.4. Nanohybrid Fe₃O₄ catalysts supported an additional bound

*Corresponding Author: Parvin Hajiabbasi (parvinhajiabbasi@yahoo.com)

4. Nanohybrid Fe_3O_4 catalysts directly bounded in the absence of silica4.1. Hybrid Pd- Fe_3O_4 nanoparticles for various C-C coupling reactions

5. Conclusion

1. Introduction

At the present time, magnetic catalysts attract enormous interest [1-5] and have an extensive variety of potential uses due to their high surface area, biocompatibility, and unique magnetic properties [6-10]. Furthermore, magnetic nanoparticles separated simply by applying the magnetic interaction using a magnetic field [11-14].

In the family of nanomagnetic materials, magnetite Fe_3O_4 exhibits excellent application such as magnetic bio-separations [15], drug delivery [16, 17], magnetic resonance imaging (MRI) [18], hyperthermia treatment of cancer cells [19, 20], and catalysts [21, 22]. Thus, we

investigate the existence and preparation of some types of Fe_3O_4 nanoparticles and their hybrids as catalysts in this study.

2. Various types of Fe_3O_4 nanohybrid catalysts

Most Schemes for iron-based nanoparticles recovery is the result of the magnetic particle (Fe , Fe_3O_4 , Fe_2O_3 , etc.) as a support which is announcer to a different catalytically active metal [23]. Catalyst training is performed when the second metal [24-26] or organo catalyst [27, 28] is anchored via a linker to the nanoparticle directly or instead of a protective polymer [29, 30] or silica coating [31, 32]. As depicted in **Figure 1**, some clusters have devolved a series of magnetic nanoparticles as beneficial catalysts in organic transformations.

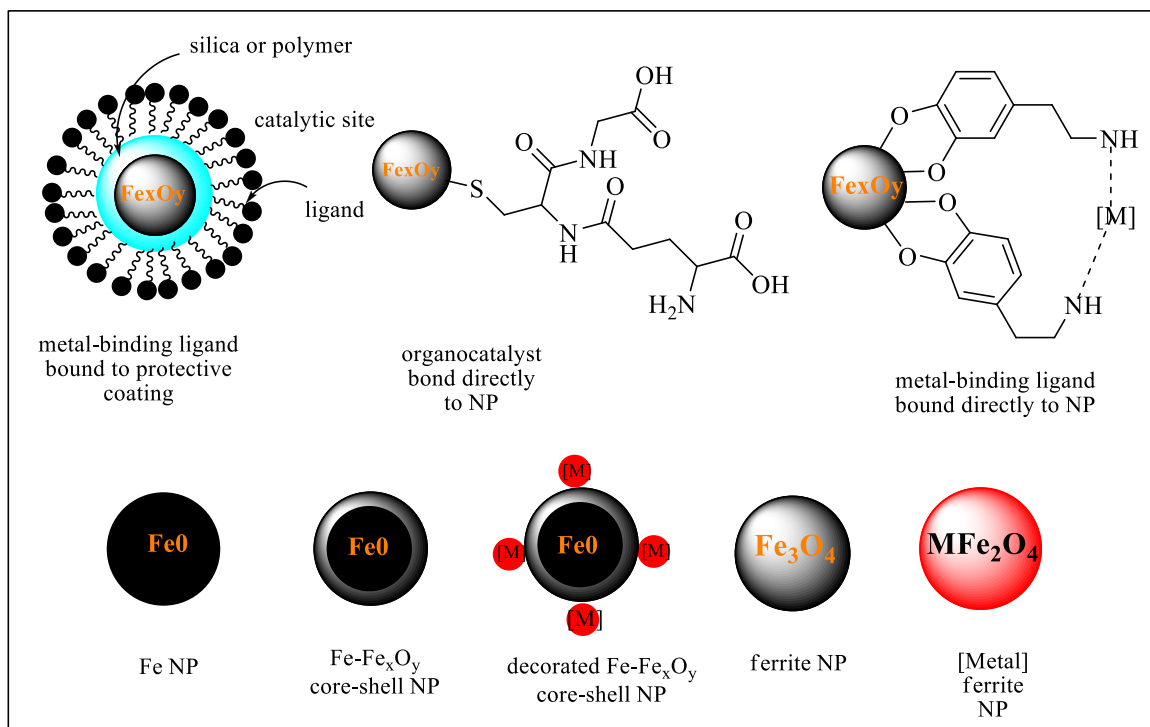


Figure 1. Various types of magnetically nanoparticles

3. Nanohybrid Fe_3O_4 catalysts having silica as protective coating

Some types of nanohybrid Fe_3O_4 catalysts having silica as protective coating (1-7) are displayed in the **Figure 2**.

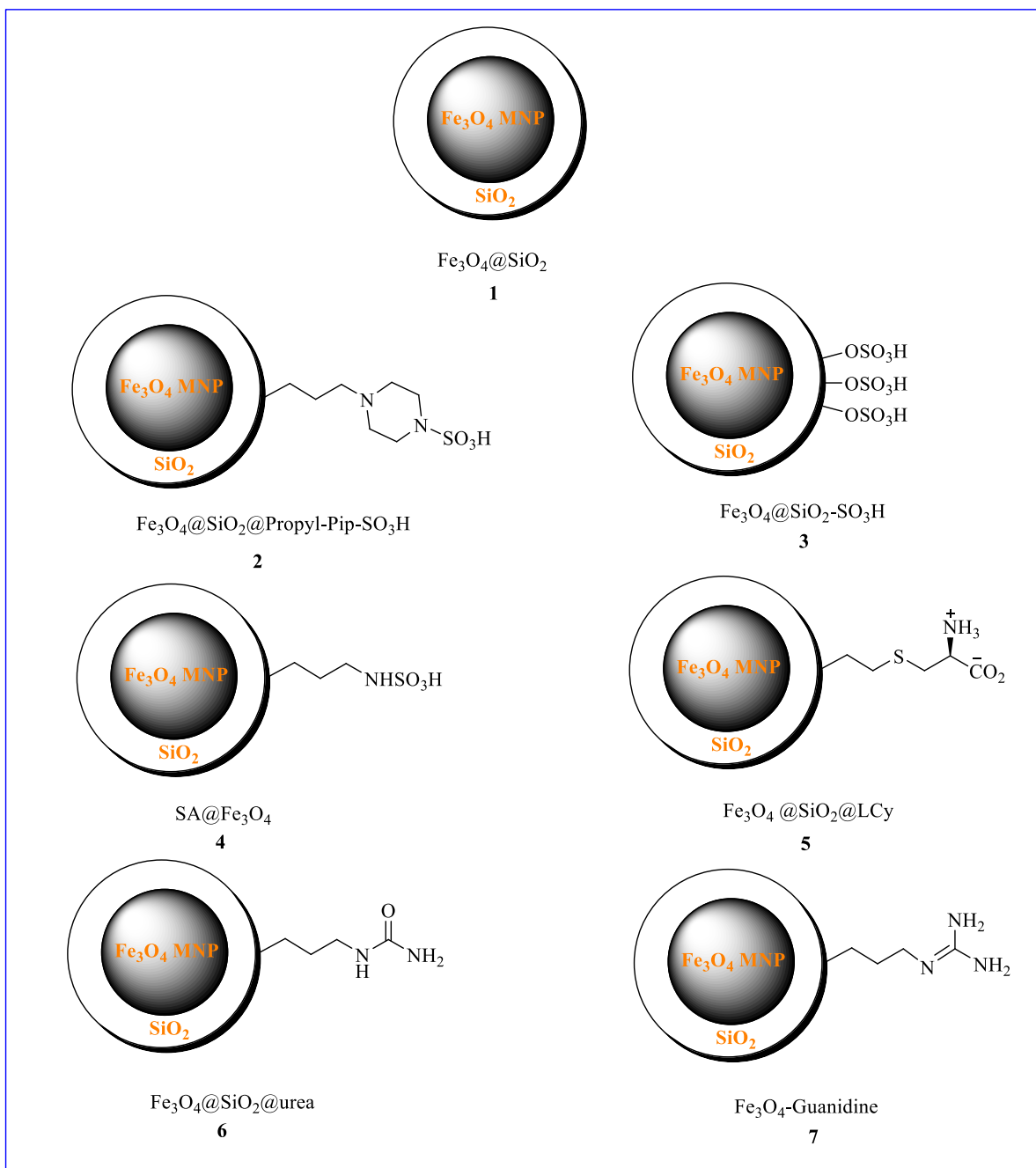
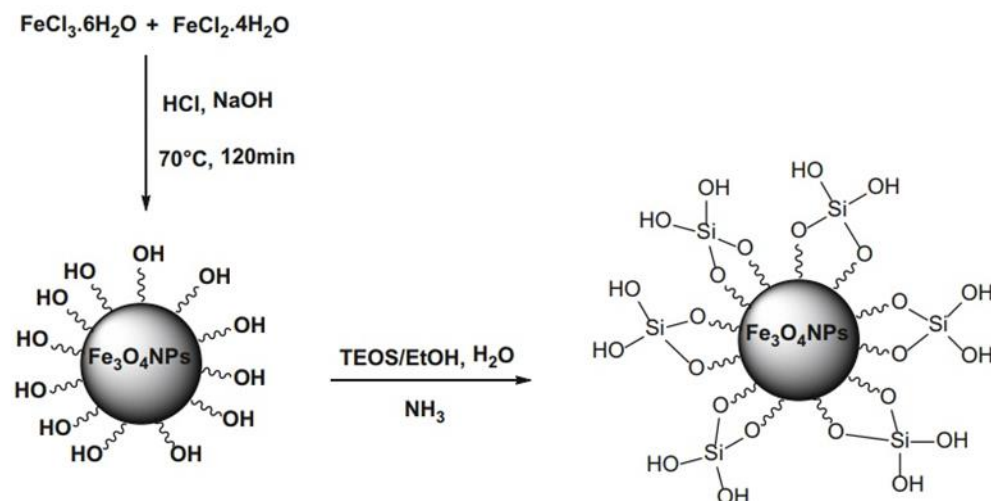


Figure 2. Typical nanohybrid Fe_3O_4 catalysts having silica coating

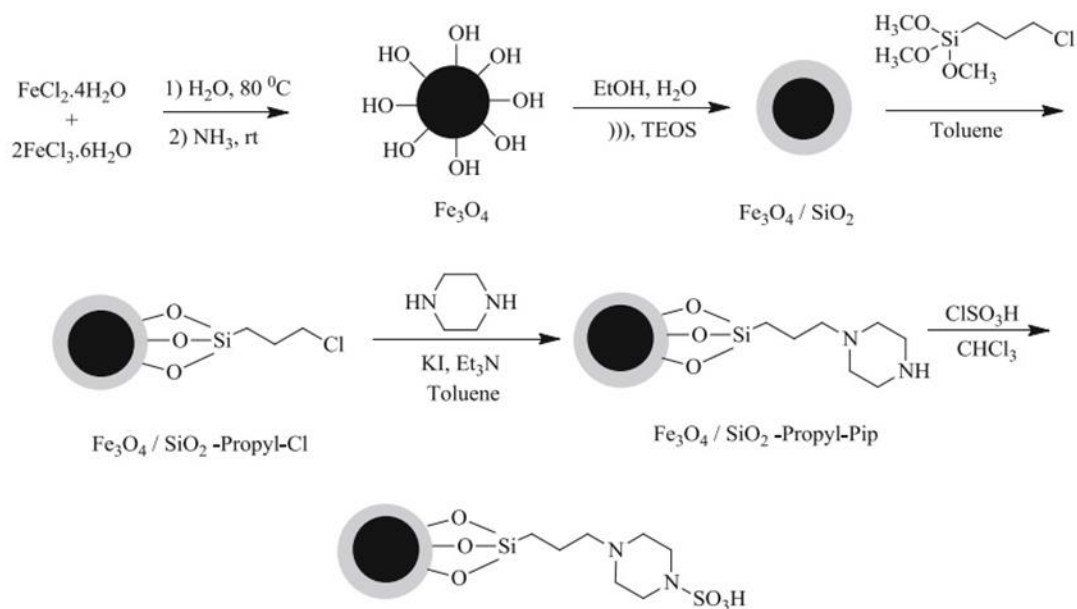
$\text{Fe}_3\text{O}_4@SiO_2$ nanoparticles (**1**) were prepared according to **Scheme 1** procedure by Hu *et al.* [33] using the chemical co-precipitation method. In this procedure, $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ and $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ were dissolved in aqueous HCl. Then, aqueous NaOH was added under vigorous stirring to produce black precipitate instantly [34].



Scheme 1. Synthetic steps of preparing $\text{Fe}_3\text{O}_4\text{@SiO}_2$ nanoparticles (1) [34]

The synthetic method for preparing the $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -PropylPip- SO_3H magnetic nanoparticles (MNPs) is shown in **Scheme 2** [35]. In the procedure, silica was coated on Fe_3O_4 MNPs, then condensation of hydroxyl groups of MSNPs with (3-chloropropyl) trimethoxysilane (CPTMS) yielded $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -Propyl-Cl MNPs. Subsequently, the reaction of the chloro groups

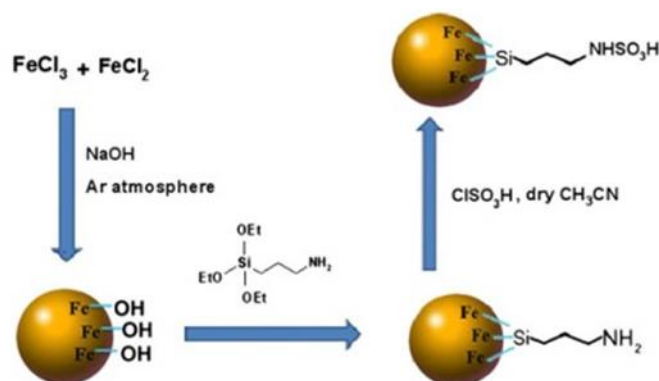
of $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -Propyl-Cl with the amine group of piperazine gained $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -supported piperazine ($\text{Fe}_3\text{O}_4/\text{SiO}_2$ -Propyl-Pip). At the last step, $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -Propyl-Pip was condensed with chlorosulfonic acid which produced *N*-propylpiperazine sulfonic acid-functionalized Fe_3O_4 magnetic nanoparticles ($\text{Fe}_3\text{O}_4/\text{SiO}_2$ -Propyl-Pip- SO_3H).



Scheme 2. Preparation of $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -Propyl-Pip- SO_3H magnetic nanoparticles (2) [35]

In this protocol, for surface modification, magnetic nanoparticles were covered with APTES to achieve aminofunctionalized magnetic nanoparticles. Finally, reaction of amino groups

and chlorosulphuric acid yielded SA-MNPs (sulphamic acid-functionalized magnetic Fe_3O_4 nanoparticles) (**Scheme 3**) [36].



Scheme 3. Preparation of SA-MNPs (sulphamic acid functionalized magnetic Fe_3O_4 nanoparticles) [36]

In addition, the preparation of some other magnetic nanoparticles was found to have silica as protective coating in the reported articles such as $\text{Fe}_3\text{O}_4@ \text{SiO}_2\text{-SO}_3\text{H}$ [37], $\text{Fe}_3\text{O}_4@ \text{SiO}_2@ \text{LCy}$ [38], $\text{Fe}_3\text{O}_4/\text{SiO}_2\text{-urea}$ [39], MNPs-Guanidine [40], and etc.

3.1 Nanohybrid Fe_3O_4 catalysts supported heteropolyacids

Some types of nanohybrid Fe_3O_4 catalysts having silica supported heteropolyacids (**8-10**) are indicated in the **Figure 3**.

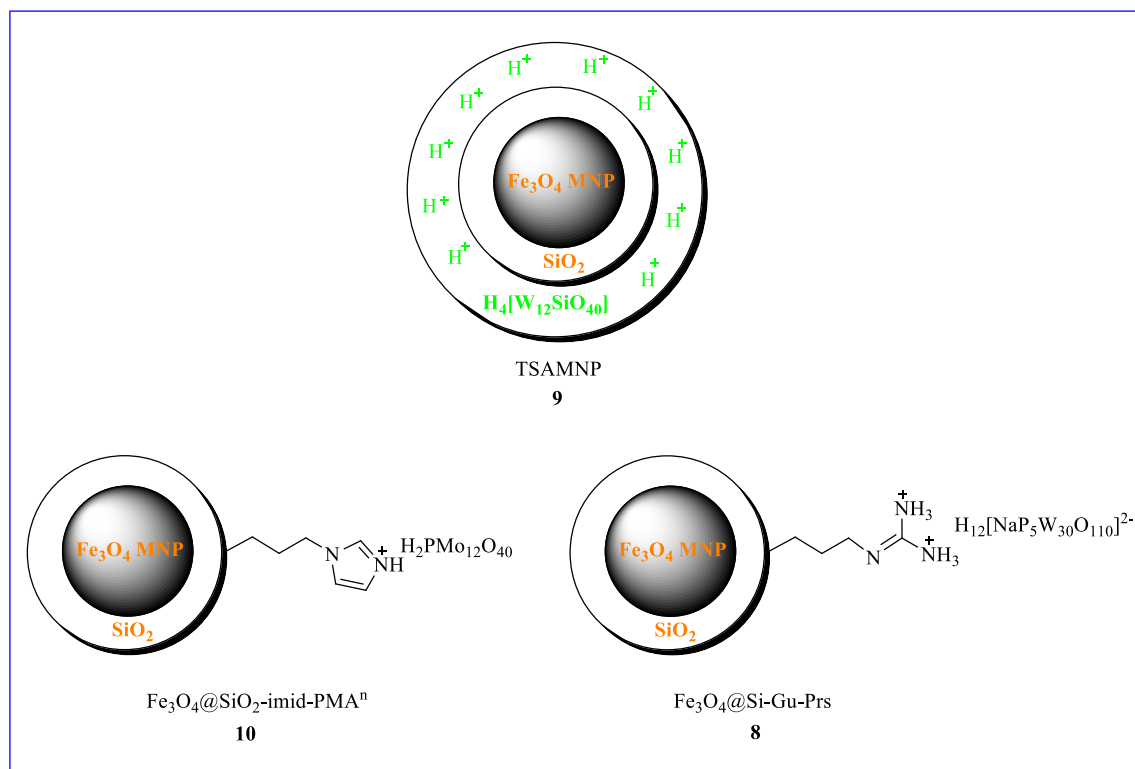
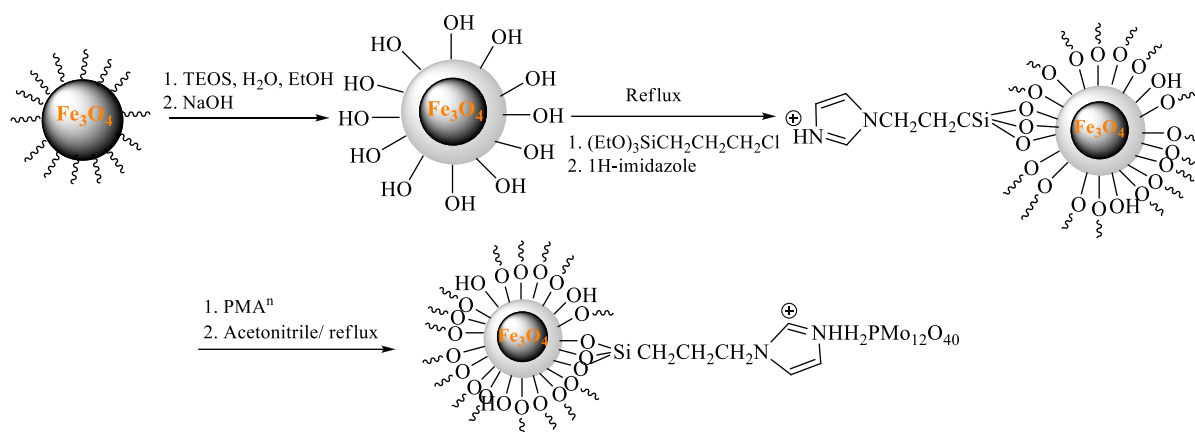


Figure 3. Typical nanohybrid Fe_3O_4 catalysts having silica supported heteropolyacids

$\text{Fe}_3\text{O}_4@ \text{SiO}_2\text{-imid-H}_3\text{PMo}_{12}\text{O}_{40}$ nanoparticles (**10**) were produced from immobilization of phosphomolybdic acid nanoparticles on imidazole functionalized $\text{Fe}_3\text{O}_4@ \text{SiO}_2$ [41]. In this procedure, $\text{Fe}_3\text{O}_4@ \text{SiO}_2$ was added to the solution of 3-chlorotriethoxypropylsilane and

imidazole in *p*-xylene to prepare $\text{Fe}_3\text{O}_4@ \text{SiO}_2\text{-imid}$. Then, $\text{Fe}_3\text{O}_4@ \text{SiO}_2\text{-imid}$ was added to an acetonitrile solution of PMA^n . Likewise, the similar process was used for the synthesis of $\text{Fe}_3\text{O}_4@ \text{SiO}_2\text{-imid-PMA}^b$ ($\text{PMA}^n = \text{nano H}_3\text{PMo}_{12}\text{O}_{40}$, $\text{PMA}^b = \text{H}_3\text{PMo}_{12}\text{O}_{40}$) (**Scheme 4**).



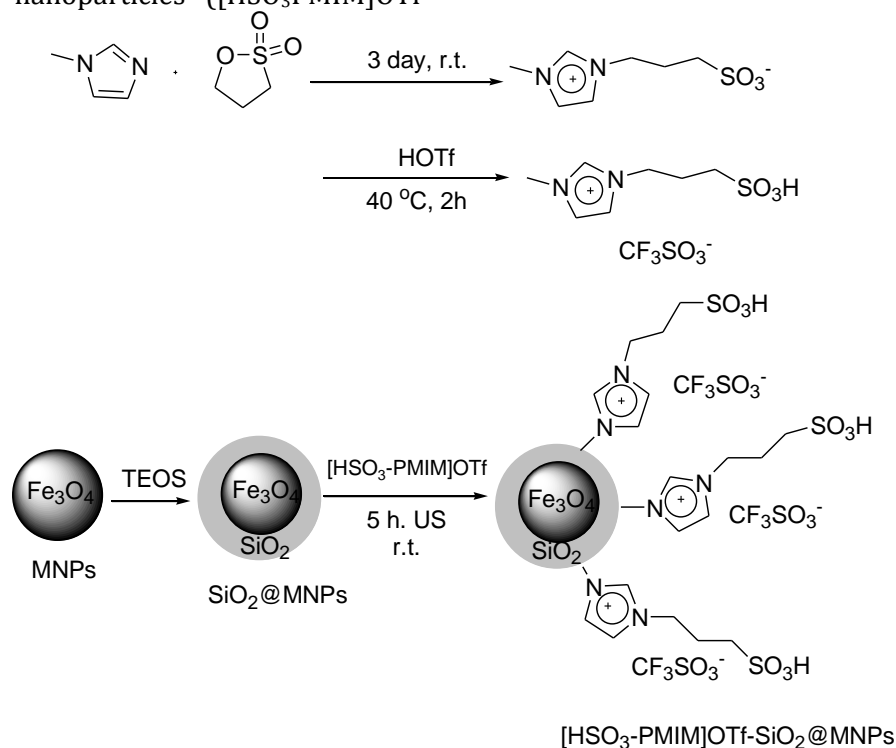
Scheme 4. Synthetic steps of $\text{Fe}_3\text{O}_4@\text{SiO}_2\text{-imid-PMA}^n$

Furthermore, the preparation of some other magnetic nanoparticles was found to have silica supported heteropolyacids reported in articles such as $\text{Fe}_3\text{O}_4@\text{Si-Gu-Prs}$ (**8**) [42], TSAMNP catalyst (**9**) [43], and etc.

3.2 Nanohybrid Fe_3O_4 catalysts supported ionic liquids

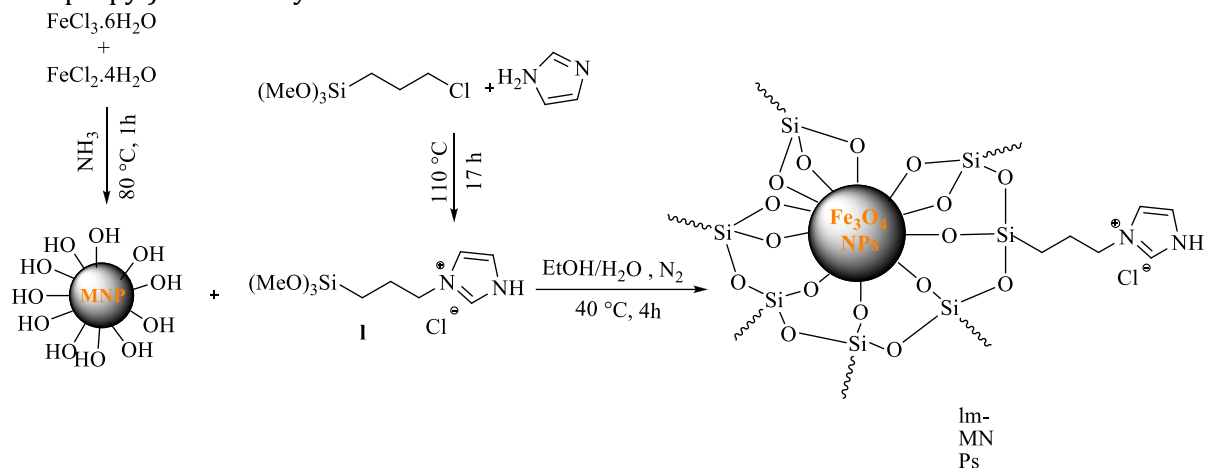
The synthetic procedure of acidic IL supported on magnetic nanoparticles ($[\text{HSO}_3\text{PMIM}]\text{OTf}$ -

$\text{SiO}_2@\text{MNPs}$) is demonstrated in **Scheme 5**. The corresponding ionic liquid $[\text{HSO}_3\text{PMIM}]\text{OTf}$ was produced by treatment of 1-methyl-3*H*-imidazole with 1,3-propanesultone, followed by treatment with HOTf. Finally, the silica coated magnetite nanoparticles was treated with $[\text{HSO}_3\text{PMIM}]\text{OTf}$ in dichloromethane by sonication to produce $[\text{HSO}_3\text{PMIM}]\text{OTf-SiO}_2@\text{MNPs}$ [44].



Scheme 5. Preparation of $[\text{HSO}_3\text{PMIM}]\text{OTf-SiO}_2@\text{MNPs}$ [44]

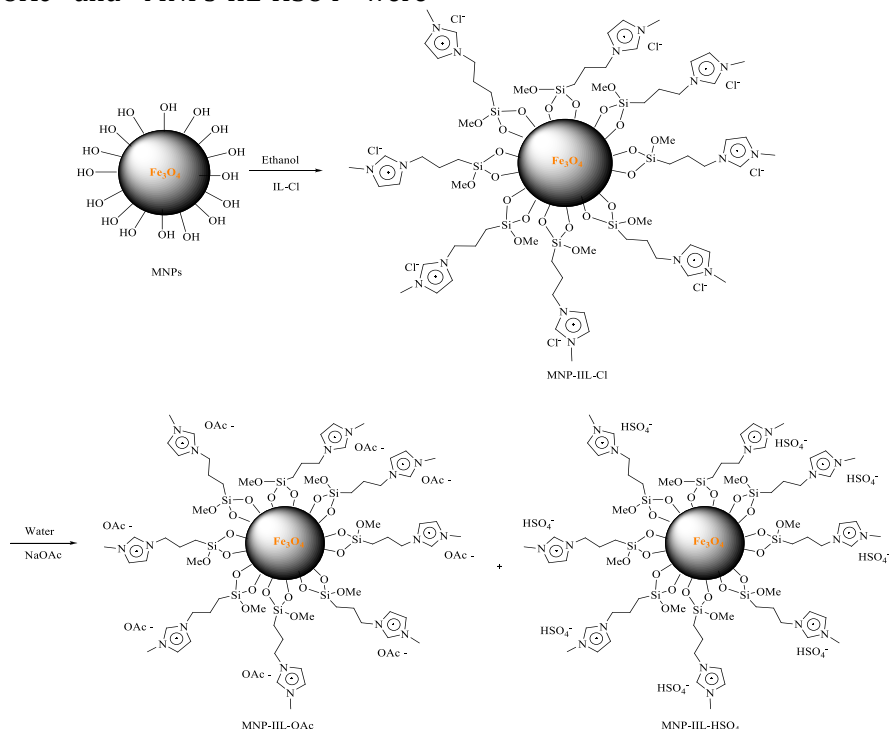
Imidazole functionalized magnetic Fe_3O_4 nanoparticles are reported by Nazari et al. [45]. In the present study, the reaction of (3-chloropropyl)-trimethoxysilane with imidazole



Scheme 6. Preparation of imidazole functionalized magnetic nanoparticles [45]

After preparing Fe_3O_4 -MNPs, 1-methyl-3-(3-trimethoxysilylpropyl) imidazolium chloride (IIL-Cl) was attained from the reaction of *N*-methyl imidazole with (3-chloropropyl) trimethoxysilane. Then, the immobilized chloride IIL on MNPs (MNP-IIL-Cl) and an excess amount of NaOAc (or KHSO_4) were added into the deionized water. As depicted in the **Scheme 7**, MNPs-IIL-OAc and MNPs-IIL- HSO_4 were

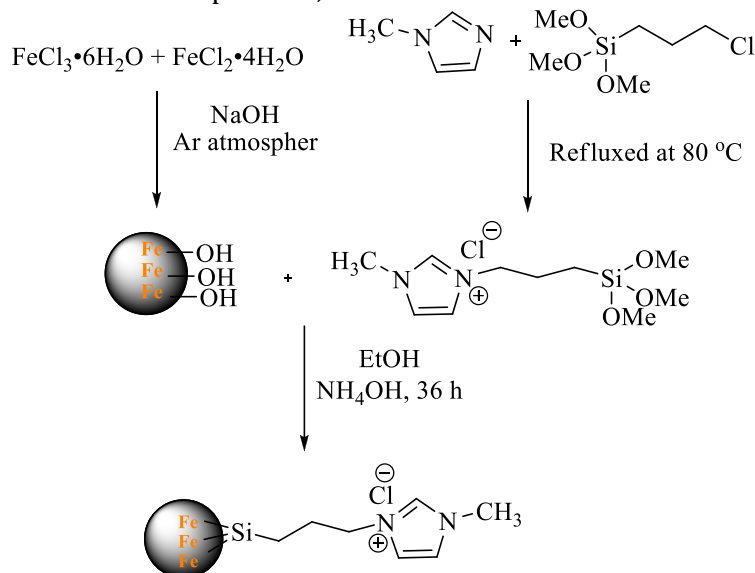
obtained as a powder. In this procedure, 1-methyl-3-(3-trimethoxysilylpropyl) imidazolium hydrogen sulfate (MNPs-IIL- HSO_4), 1-methyl-3-(3-trimethoxysilylpropyl) imidazolium acetate (MNPs-IIL-OAc), and 1-methyl-3-(3-trimethoxysilylpropyl) imidazolium chloride (MNPs-IIL-Cl) were prepared [46].



Scheme 7. Preparation steps of producing MNPs-IILs [46]

The ionic liquid 1-methyl-3-(3-trimethoxysilylpropyl) imidazolium chloride immobilized functionalized on Fe_3O_4 nanoparticles (IL-MNPs) was further reported by Safari and Zarnegar. The synthetic steps are shown in the the **Scheme 8**. In this protocol, *N*-

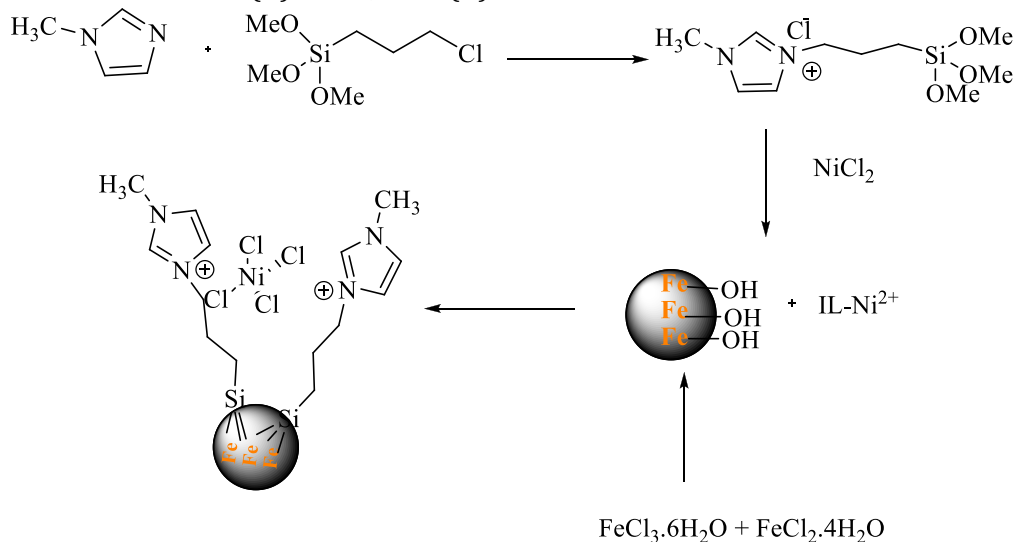
methyl imidazole reacted with (3-chloropropyl) trimethoxysilane to prepare 1-methyl-3-(3-trimethoxysilylpropyl) imidazolium chloride (IL). Then, IL was added to the external surface of MNPs to attain IL-MNPs [47].



Scheme 8. Preparation steps of IL- Fe_3O_4 nanoparticles [47]

As illustrated in the **Scheme 9**, IL-Ni(II)-functionalized magnetic Fe_3O_4 nanoparticles are prepared. The IL addition to an acetonitrile solution of NiCl_2 led to IL-Ni(II). Then, IL-Ni(II)

immobilized on the external surface of Fe_3O_4 nanoparticles to achieve IL-Ni(II)-MNPs as the desired product [48].

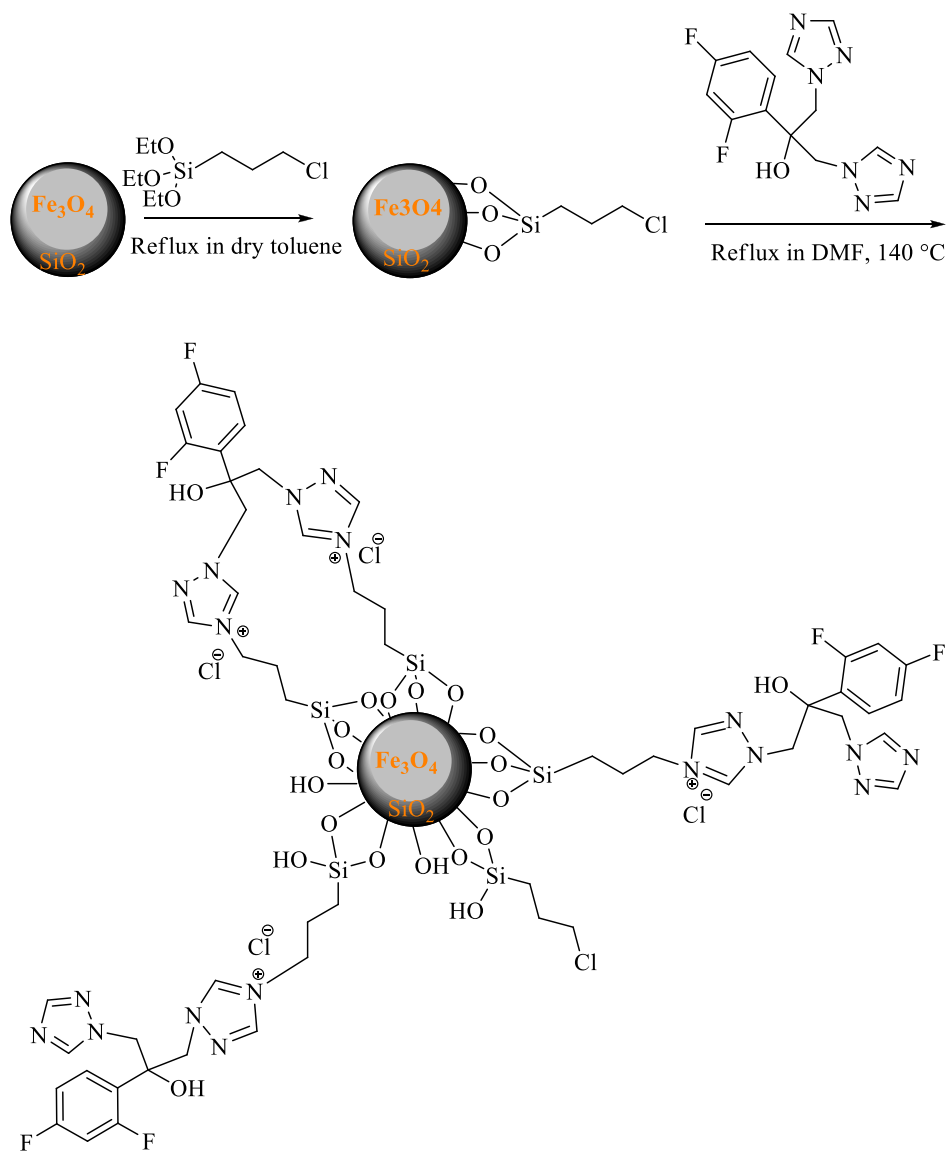


Scheme 9. IL-Ni(II)-MNPs preparation steps [48]

The $\text{Fe}_3\text{O}_4@SiO_2\sim\text{FLU}$ nanomagnetic catalyst was organized as depicted in the **Scheme 10**. Evidently, iron oxide is coated by a silica layer to immobilize organic catalyst on the surface of

inorganic support because of that organosilanes can act as a linker between the organic catalyst and the support. As reported, chloride in the

linker was replaced by nitrogen of the triazole via an S_N2 reaction [49].

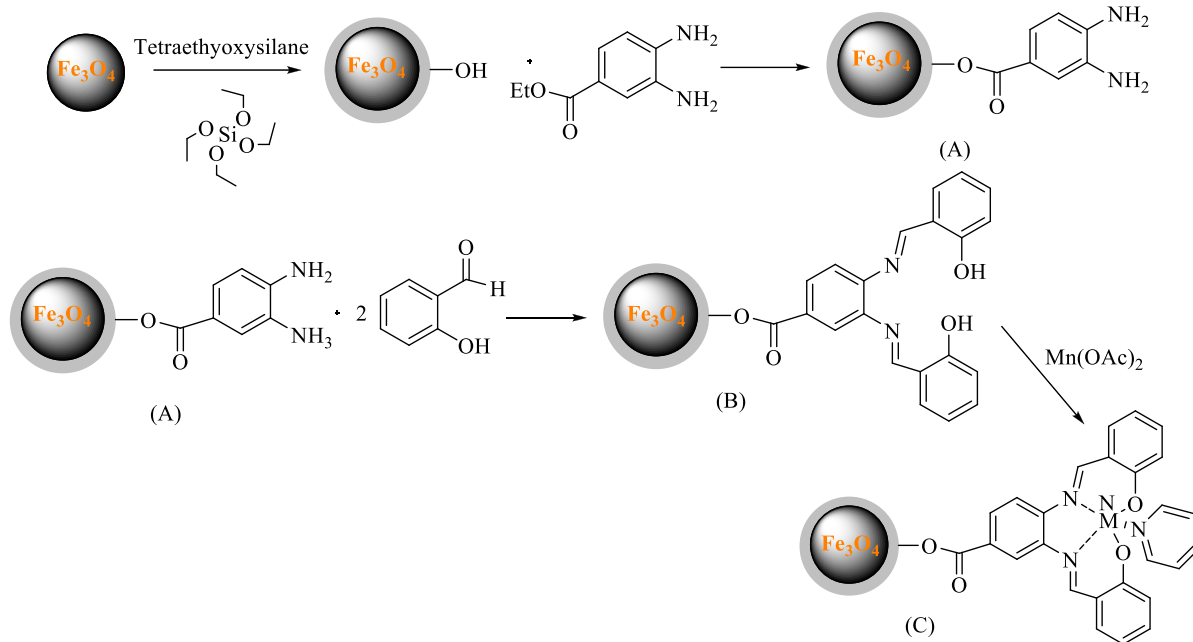


Scheme 10. $Fe_3O_4@SiO_2\sim FLU$ nanomagnetic catalyst preparation [49]

3.3 Nanohybrid Fe_3O_4 catalysts supported metal bounds

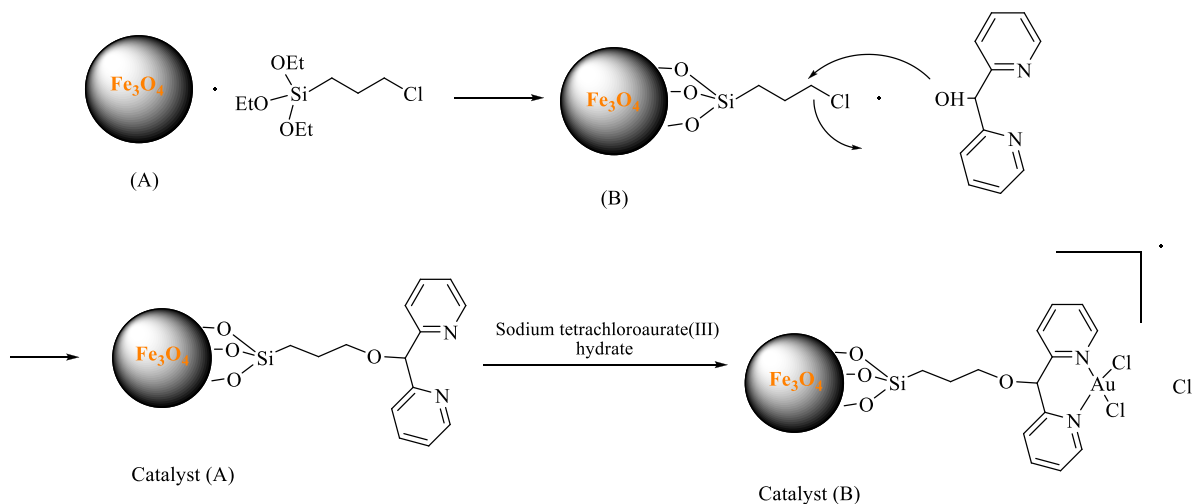
Herein, synthesis steps of manganese (III) salen complex immobilized on Fe_3O_4 nanoparticles reported by S.M. Sadeghzadeh *et al.* is demonstrated in **Scheme 11**. For the synthesis

of compound (A) MNP, Fe_3O_4/SiO_2 MNPs were added to ethyl 3,4-diaminobenzoate. Then, for synthesis of $Fe_3O_4/SiO_2/Salen/Mn$ nanoparticles (C), compound (A) was reacted with the solution of salicylaldehyde and subsequently with $Mn(OAc)_2$ [50].



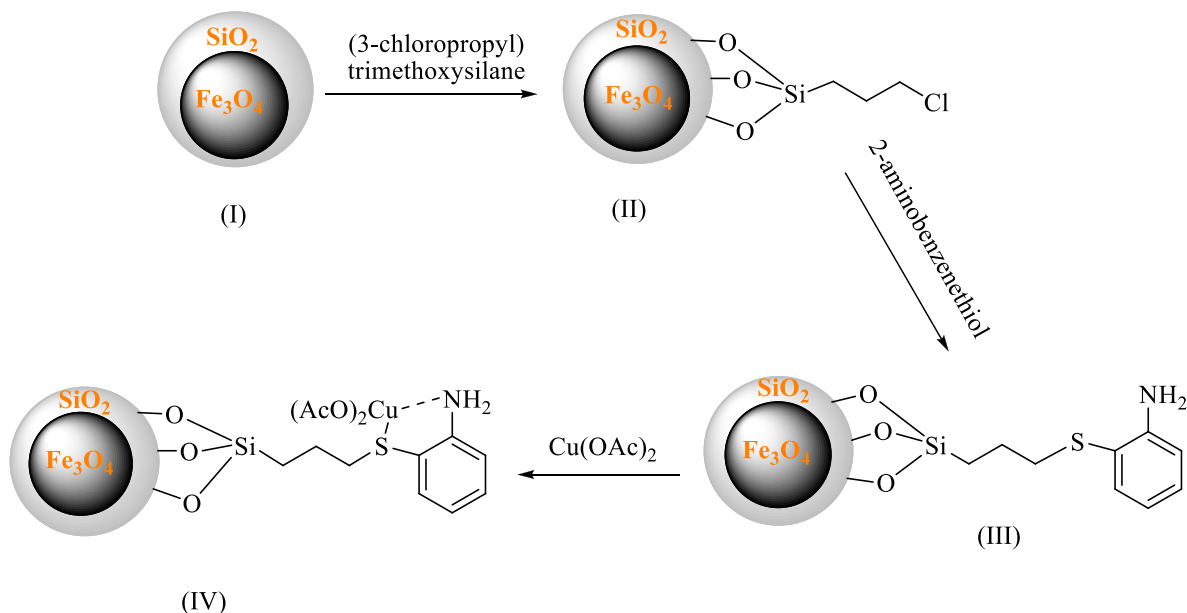
Scheme 11. Synthesis steps of $\text{Fe}_3\text{O}_4/\text{SiO}_2/\text{Salen}/\text{Mn}$ nanoparticles [50]

Another Fe_3O_4 supported gold dipyrindine complex nanoparticles was formed via sodium tetrachloroaurate(III) hydrate attaching to a dipyrindine ligand (**Scheme 12**) [51].

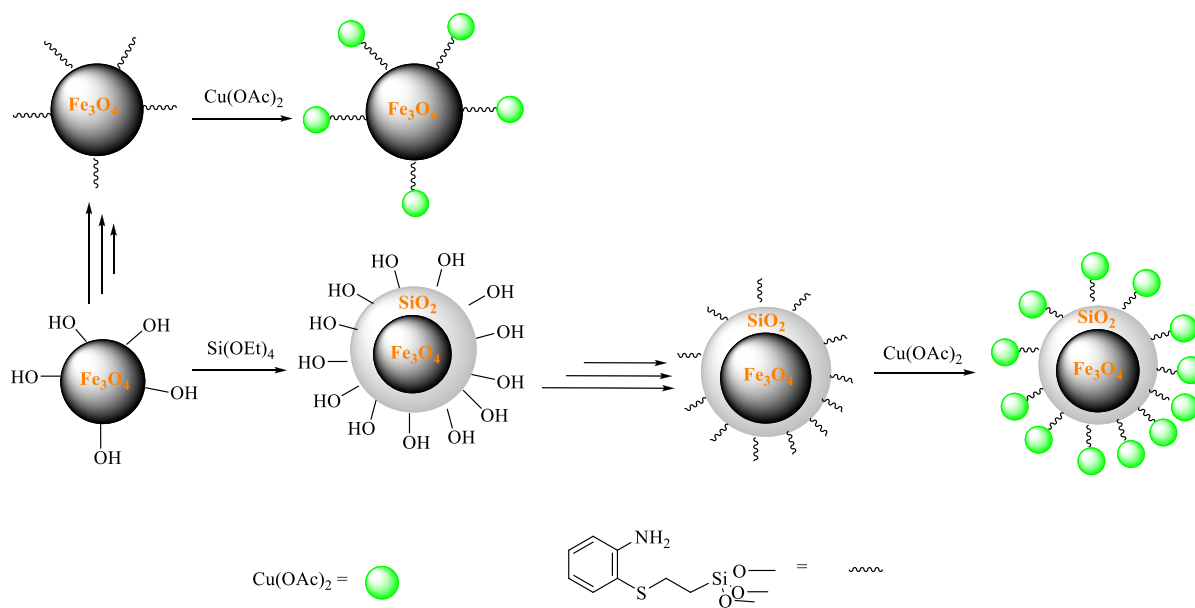


Scheme 12. Fe_3O_4 supported gold dipyrindine complex nanoparticles synthesis [51]

$\text{Cu}(\text{II})/2$ -Aminobenzenethiol complex immobilized on $\text{Fe}_3\text{O}_4/\text{SiO}_2$ NPs is reported to catalyze synthesis of 1,2,3-triazoles. As depicted in **Scheme 13** and **Scheme 14**, $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -(3-chloropropyl) trimethoxysilane was prepared to react with 2-aminobenzenethiol and subsequently, copper acetate was added to the mixture in order to prepare $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -ABT/ $\text{Cu}(\text{OAc})_2$ [52].



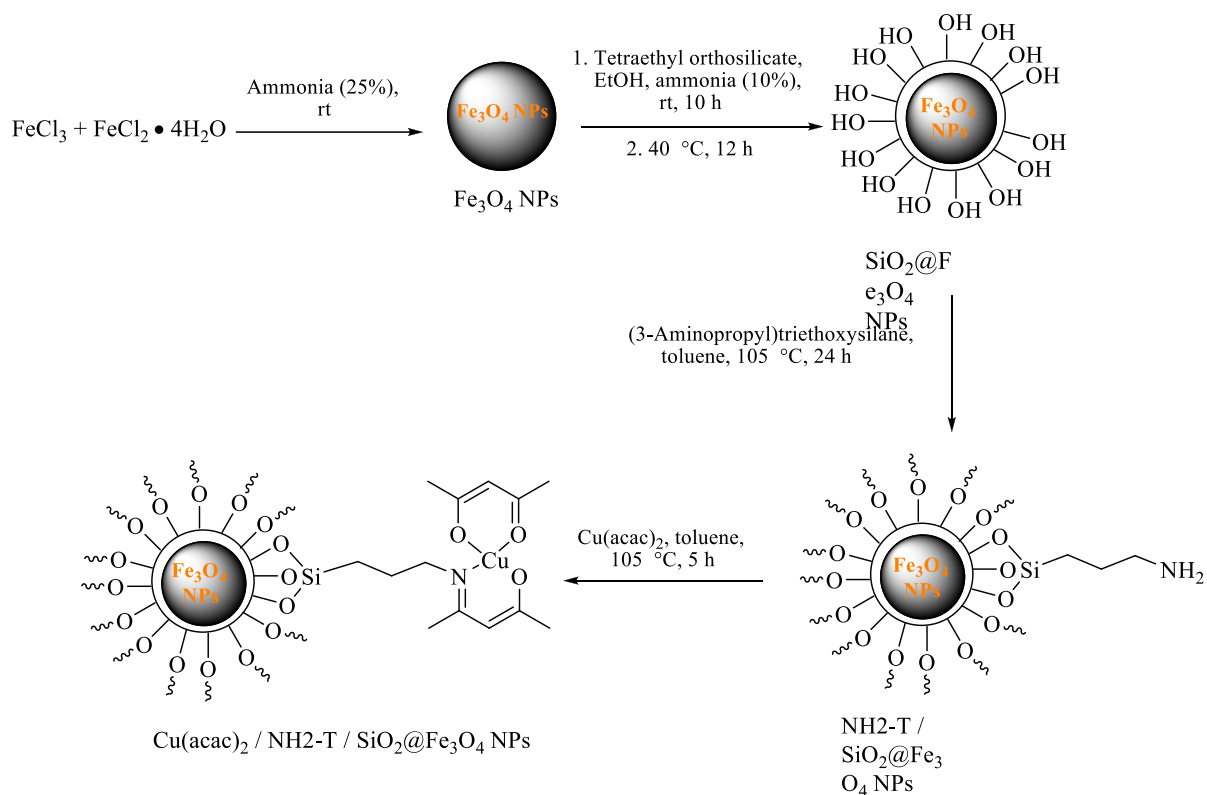
Scheme 13. $\text{Cu}(\text{OAc})_2/2\text{-aminobenzethiol}$ complex coated on $\text{Fe}_3\text{O}_4/\text{SiO}_2$ NPs formation [52]



Scheme 14.

$\text{Cu}(\text{acac})_2/\text{NH}_2\text{-T}/\text{SiO}_2@\text{Fe}_3\text{O}_4$ NPs were prepared through immobilization of copper(II) acetylacetonate on the external surface of amine-terminated $\text{Fe}_3\text{O}_4/\text{SiO}_2$ NPs (**Scheme 15**).

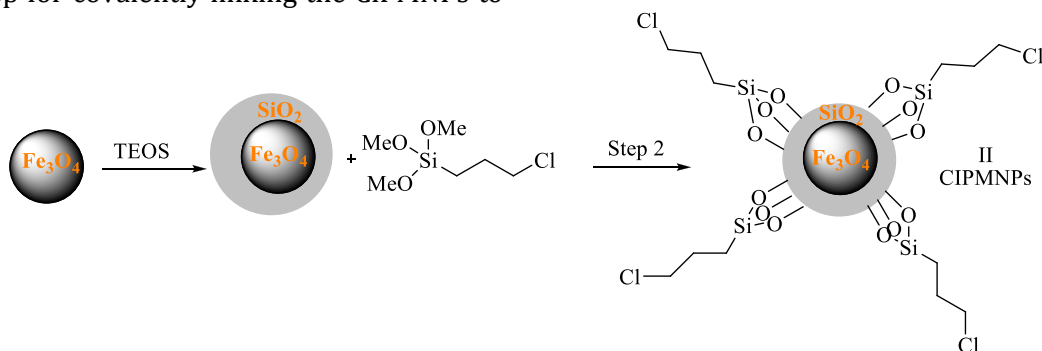
In this protocol, the synthesized $\text{NH}_2\text{-T}/\text{SiO}_2@\text{Fe}_3\text{O}_4$ NPs was added to a solution of $[\text{Cu}(\text{acac})_2]$ [53].



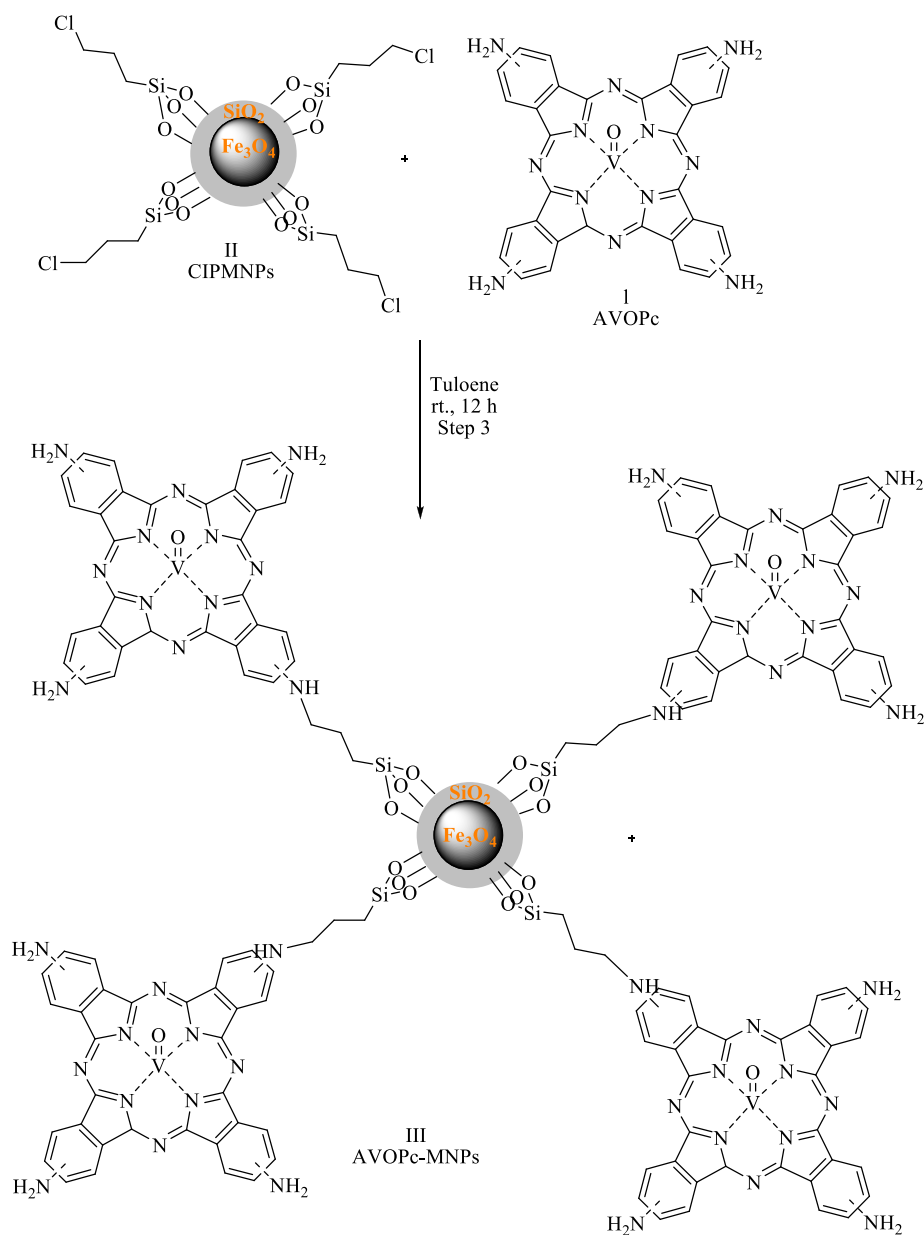
Scheme 15. Stepwise synthesis of $\text{Cu}(\text{acac})_2/\text{NH}_2\text{-T}/\text{SiO}_2@\text{Fe}_3\text{O}_4$ NPs [53]

$\text{Fe}_3\text{O}_4@\text{SiO}_2@\text{SiO}_2(\text{CH}_2)_3@\text{AVOPc}$ was formed by covalent binding of an amino vanadium oxo phthalocyanine, on the surface of $\text{Fe}_3\text{O}_4/\text{SiO}_2$ NPs [54]. $\text{Fe}_3\text{O}_4@\text{SiO}_2@\text{SiO}_2(\text{CH}_2)_3\text{Cl}$ (CIPMNPs) were prepared as depicted in **Scheme 16**. In the next step for covalently linking the CIPMNPs to

AVOPc, CIPMNPs was sonicated and subsequently, they were added to the AVOPc in order to produce $\text{Fe}_3\text{O}_4@\text{SiO}_2@\text{SiO}_2(\text{CH}_2)_3@\text{AVOPc}$ (AVOPc-MNPs) (**Scheme 17**) [54].



Scheme 16. Chloro functionalized magnetic nano particles (II) formation [54]

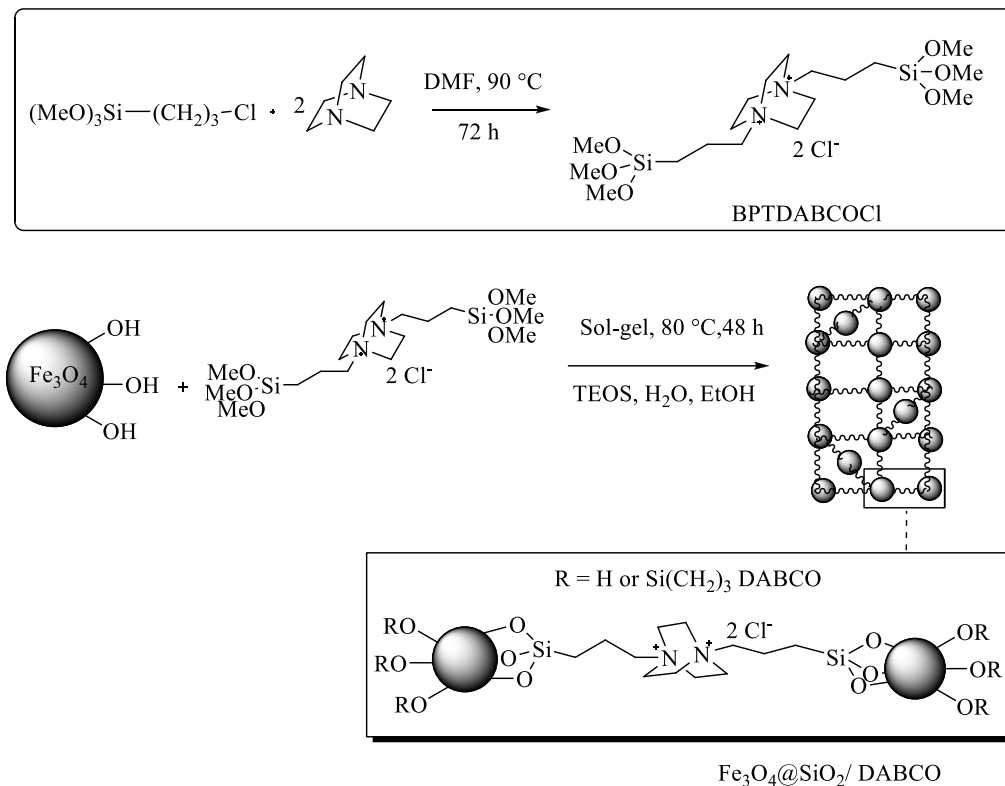


Scheme 17. Synthesis of AVOPc-MNPs [54]

Another type of magnetic nano particles based on a biimidazole Cu(I) complex was produced by covalent binding of biimidazole on chloride-functionalized Fe₃O₄/SiO₂ NPs, followed by reacting with CuI [55].

3.4. Nanohybrid Fe₃O₄ catalysts supported an additional bound

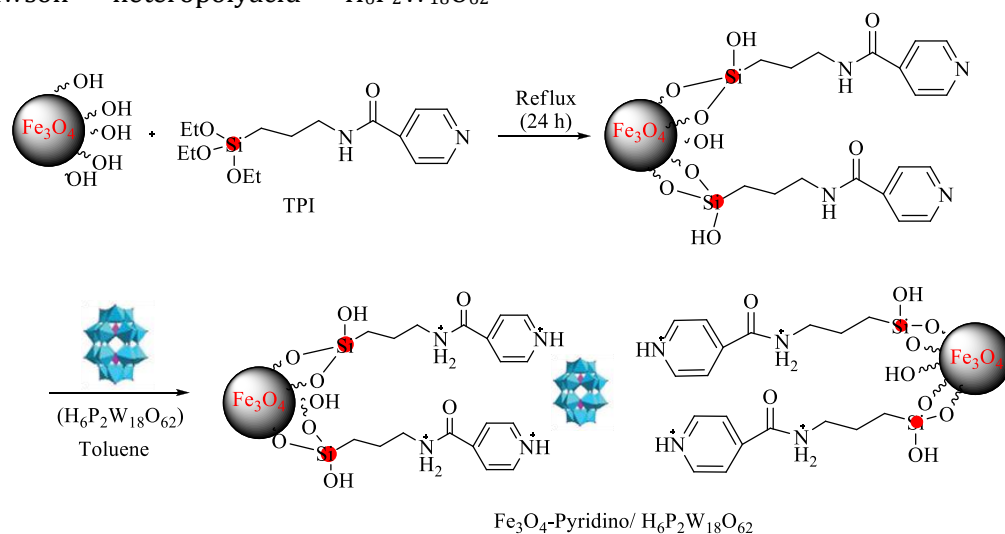
An organic-inorganic type of silica with ionic liquid basis was produced as indicated in **Scheme 18**. In this protocol, diazoniabicyclo [2.2.2] octane dichloride groups, [(MeO)₃Si(CH₂)₃N⁺(CH₂CH₂)₃N⁺(CH₂)₃Si(OMe)₃]Cl₂, were produced as a precursor reagent to achieve the desired nano particles [56].



Scheme 18. Preparation steps of Fe₃O₄@SiO₂/DABCO [56]

An inorganic-organic type of MNPs H₆P₂W₁₈O₆₂/pyridino- Fe₃O₄ (HPA/TPI-Fe₃O₄) produced by Tayebbe *et al.* (**Scheme 19**). The Wells-Dawson heteropolyacid H₆P₂W₁₈O₆₂

immobilized on the external surface of Fe₃O₄ nanoparticles with *N*-[3-(triethoxysilyl)propyl]isonicotinamide (TPI) linker [57].



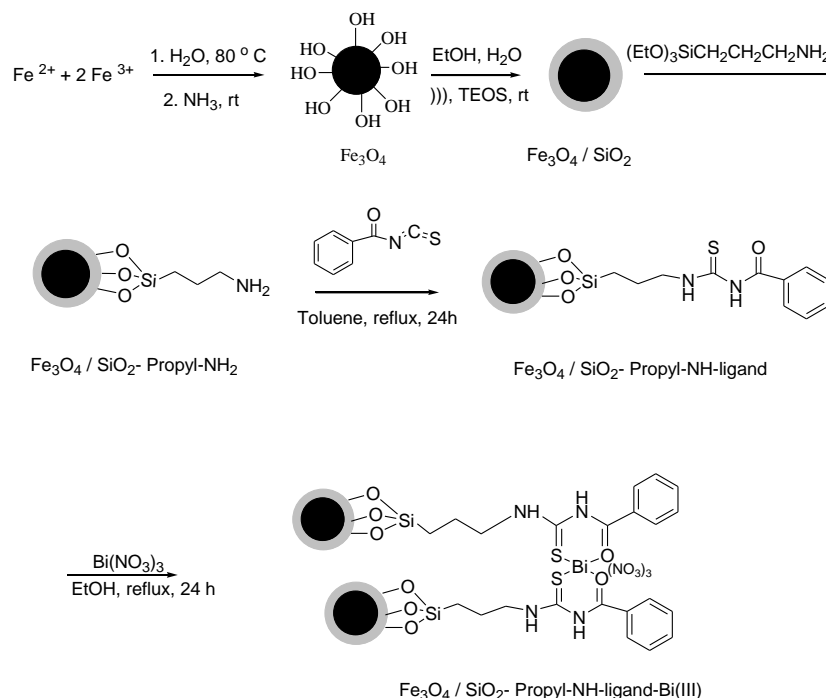
Scheme 19. HPA/TPI-Fe₃O₄ nano particles as catalyst [57]

The *N*-propylcarbamothioyl benzamide complex of Bi(III) fixed on Fe₃O₄/SiO₂ NPs has been reported by Mobinikhaledi *et al.* [58]. In this report, Fe₃O₄/SiO₂ reacted with (3-aminopropyl) triethoxysilane (APTES) to yield

Fe₃O₄/SiO₂-NH₂ MNPs. Then, the condensation reaction of amino groups of Fe₃O₄/SiO₂-NH₂ with benzoyl isothiocyanate led to Fe₃O₄/SiO₂-supported carbamothioyl benzamide (Fe₃O₄/SiO₂-NH-ligand) formation. Lastly, the

reaction of $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -supported carbamothioyl benzamide with $\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$ led to $\text{Bi}(\text{III})$

complex of $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -NH-ligand magnetic nanoparticles (MNPs) (**Scheme 20**).

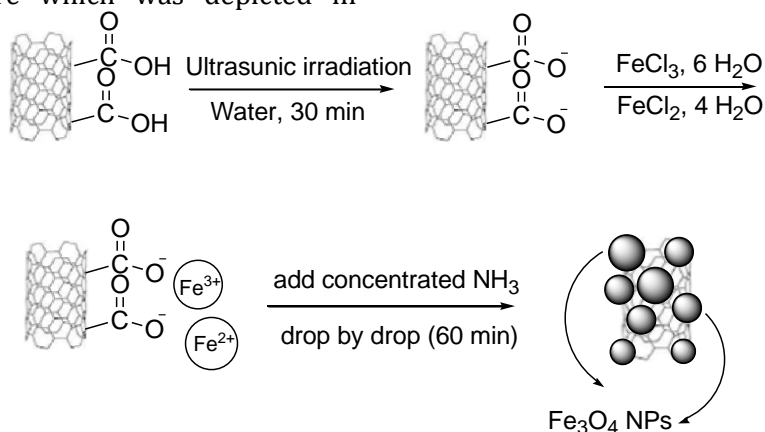


Scheme 20. Preparation of $\text{Fe}_3\text{O}_4/\text{SiO}_2$ -propyl-NH-ligand-Bi(III) MNPs [58]

4. Nanohybrid Fe_3O_4 catalysts directly bounded in the absence of silica

Multi-walled carbon nanotubes supported Fe_3O_4 nano particles is prepared according to the synthetic procedure which was depicted in

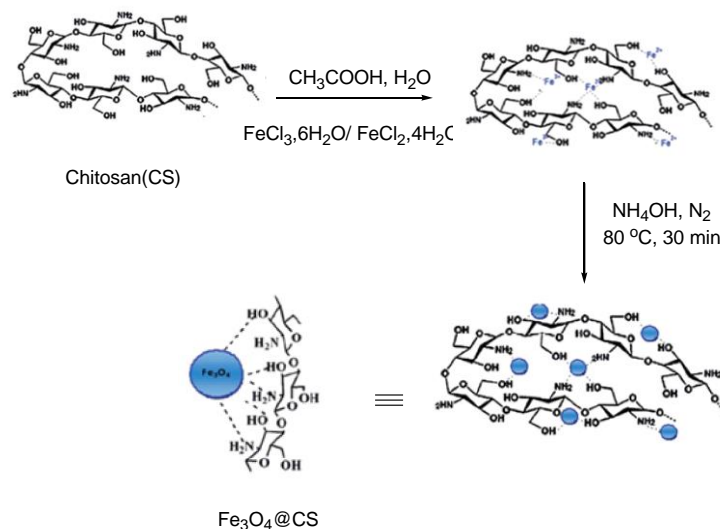
Scheme 21. In this study, carboxylic acid functionalized MWCNTs used as starting materials. Finally, the solution of NH_3 was added to produce black magnetic Fe_3O_4 NPs/MWCNTs [59].



Scheme 21. Simplified schematic exhibition of the synthesis of Fe_3O_4 NPs/MWCNTs [59]

As the synthetic steps are illustrated in the **Scheme 22**, chitosan-coated Fe_3O_4 ($\text{Fe}_3\text{O}_4/\text{CS}$) synthesized via in situ co-precipitation of Fe^{2+}

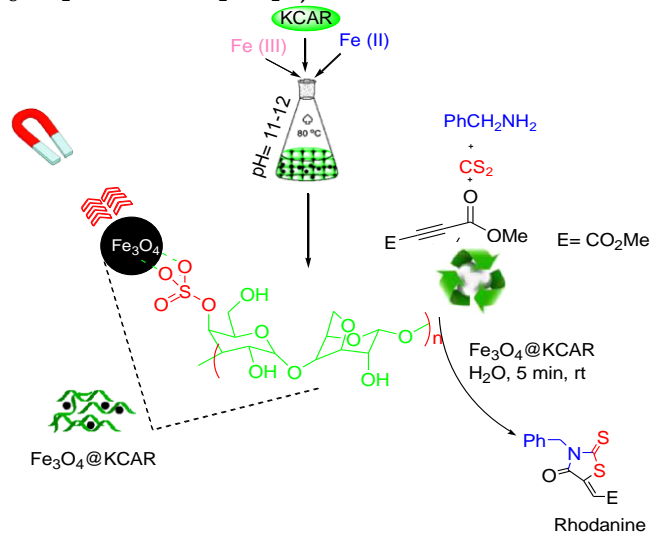
and Fe^{3+} ions with an aqueous solution of chitosan [60].



Scheme 22. Preparation steps for fabricating heterogeneous $\text{Fe}_3\text{O}_4 @ \text{CS}$ nanoparticles [60]

Herein, $\text{Fe}_3\text{O}_4 @ \text{KCAR}$ was synthesized in the presence of natural κ -carrageenan (KCAR) biopolymer (**Scheme 23**). KCAR dissolved in water is added to $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ and $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$,

and then aqueous ammonia was added to the solution in order to produce the desired product [61].



Scheme 23. A schematic pathway for synthesis of $\text{Fe}_3\text{O}_4 @ \text{KCAR}$ and rhodanine [61]

A dehydroascorbic acid covered Fe_3O_4 NPs (DHAA- Fe_3O_4) is also synthesis as the structure of the catalyst is illustrated in the **Figure 4**. For preparing DHAA-capped magnetite nanoparticles (DHAA- Fe_3O_4) $\text{Fe}(\text{OH})_3$ solution

was prepared by addition of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ aqueous solution to NaHCO_3 solution. Subsequently, a solution of vitamin C was reacted gradually to Fe^{3+} [62].

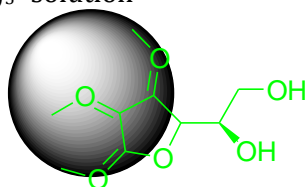


Figure 4. DHAA-capped magnetite nanoparticles [62]

In addition, Fe_3O_4 -proline MNPs was produced with no additional linkers as shown in the **Figure 5**. In this process $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ and $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ salts were dissolved in deionized

water and subsequently, proline and NH_4OH solution was added to produce the desired Fe_3O_4 -proline nanoparticles [63].

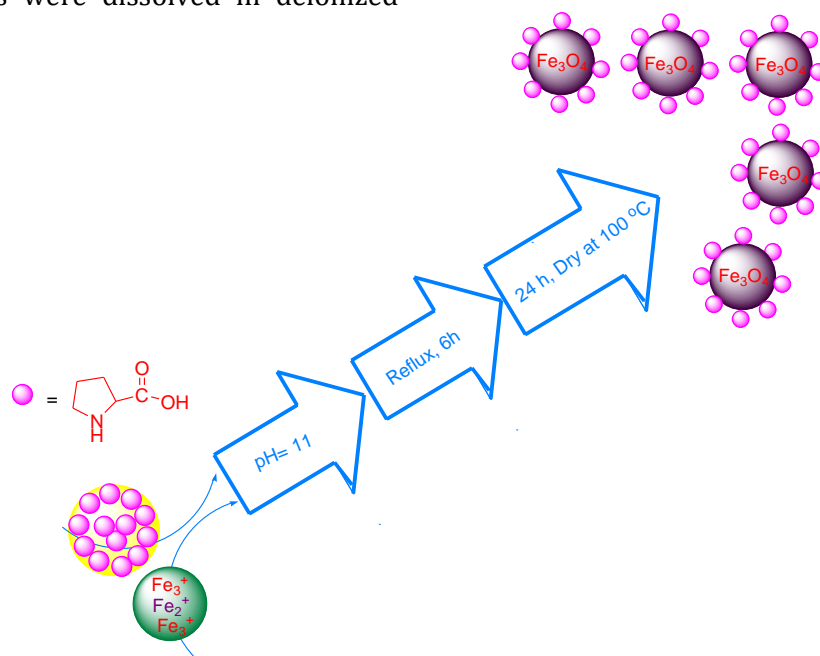


Figure 5. Preparation of Fe_3O_4 -proline MNPs [63]

Moreover, $\text{Pd}@$ agarose- Fe_3O_4 nanoparticles were synthesized. In this protocol, palladium nanoparticles supported on an agarose hydrogel which is attached to magnetic Fe_3O_4 nanoparticles [64].

The $\text{Fe}_3\text{O}_4/\text{ZIF-8}$ nanoparticles were prepared via the reaction between 2-methylimidazole (MeIM) and zinc nitrate in the presence of Fe_3O_4 NPs as displayed in the **Figure 6** [65, 66].

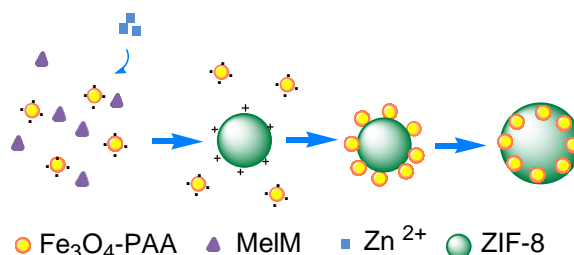
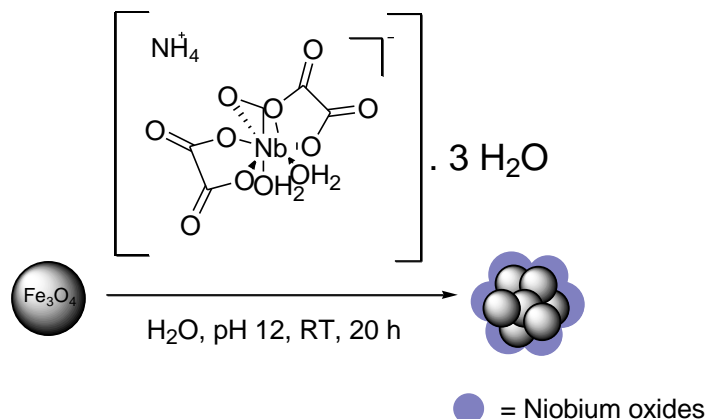


Figure 6. $\text{Fe}_3\text{O}_4/\text{ZIF-8}$ particles preparation. PAA=polyacrylic acid [65, 66]

A magnetic organic-inorganic Fe_3O_4 NP was prepared and called (Fe_3O_4 /PAA- SO_3H) sulfonated-phenylacetic acid immobilized on Fe_3O_4 NPs. Phenylacetic acid immobilized initially on manufactured Fe_3O_4 NPs. Then, the $\text{Fe}_3\text{O}_4/\text{PAA}$ was sulfonated by numerous amounts of chlorosulfonic acid to give $\text{Fe}_3\text{O}_4/\text{PAA-}\text{SO}_3\text{H}$ [67].

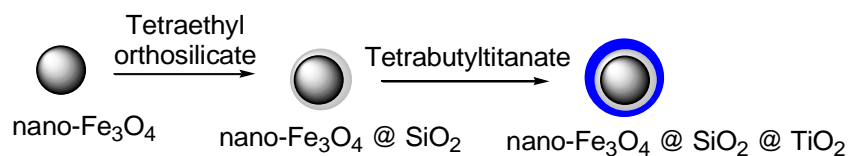
The $\text{Fe}_3\text{O}_4@\text{Nb}_2\text{O}_5$ nanocatalyst was prepared by coating magnetite nanoparticles with

niobium oxide by using a simple wet impregnation method (**Scheme 24**). The $\text{Fe}_3\text{O}_4@\text{Nb}_2\text{O}_5$ nanocatalyst was formed using ammonium niobate oxalate hydrate ($\text{C}_4\text{H}_4\text{NNbO}_9 \cdot 3\text{H}_2\text{O}$) as the niobium source. The hydrolysis of the niobium precursor in alkaline medium led to aggregation of niobium hydroxides over the surface of Fe_3O_4 nanoparticles [68].



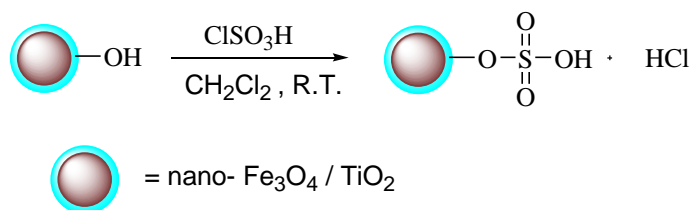
Scheme 24. Synthesis of the niobium nanocatalyst [68]

Titanium dioxide Fe_3O_4 NPs orthosilicate and tetrabutyl titanate, ($\text{Fe}_3\text{O}_4@ \text{SiO}_2@ \text{TiO}_2$) were organized via the reaction of Fe_3O_4 NPs with tetraethyl



Scheme 25. Preparation of $\text{Fe}_3\text{O}_4@ \text{SiO}_2@ \text{TiO}_2$ [69, 70]

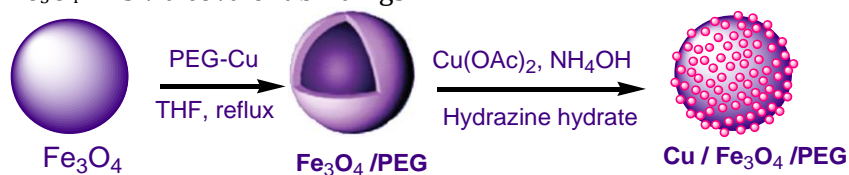
TiO_2 -coated Fe_3O_4 NPs-supported sulfonic acid ($\text{Fe}_3\text{O}_4\text{-TiO}_2\text{-SO}_3\text{H}$ (n -FTSA)) was achieved by immobilizing- SO_3H groups on the surface of nano- $\text{Fe}_3\text{O}_4\text{-TiO}_2$ (**Scheme 26**) [71].



Scheme 26. $\text{Fe}_3\text{O}_4/\text{TiO}_2$ -supported sulfonic acid nanoparticles formation [71]

Polyethylene glycol-Cu nanocomposite ($\text{Fe}_3\text{O}_4\text{-PEG-Cu}$) synthetic steps is depicted in **Scheme 27**. First, cyanuric chloride reacted with $\text{PEG}(\text{OH})_2$ to prepare PEG-Cl_4 [72]. Second, PEG-Cl_4 was linked with Fe_3O_4 NPs via covalent bindings

($\text{Fe}_3\text{O}_4\text{-PEG}$). Finally, the $\text{Fe}_3\text{O}_4\text{-PEG-Cu}$ catalyst was produced by reducing copper ammonia complexes using hydrazine hydrate on the surface of $\text{Fe}_3\text{O}_4\text{-PEG}$ nanocomposite [73].



Scheme 27. $\text{Fe}_3\text{O}_4\text{-PEG-Cu}$ nanoparticles preparation [73]

$\text{Fe}_3\text{O}_4/\text{HAp}/\text{Au}$ was prepared by magnetic metal oxides (Fe_3O_4), noble metals Au, and hydroxyapatite (HAp, hydroxyapatite). This catalyst is an efficient one for many responses

such as photocatalysis, molecular imaging, and drug delivery. Synthesis of $\text{Fe}_3\text{O}_4/\text{HAp}/\text{Au}$ composite NPs was performed in three steps as demonstrated in **Figure 7** including syntheses of

Fe_3O_4 NPs (A), magnetic hydroxyapatite ($\text{Fe}_3\text{O}_4/\text{HAp}$) NPs (B), and $\text{Fe}_3\text{O}_4/\text{HAp}/\text{Au}$ (C).

Finally, the prepared catalyst was utilized for efficient photocatalytic application [74].

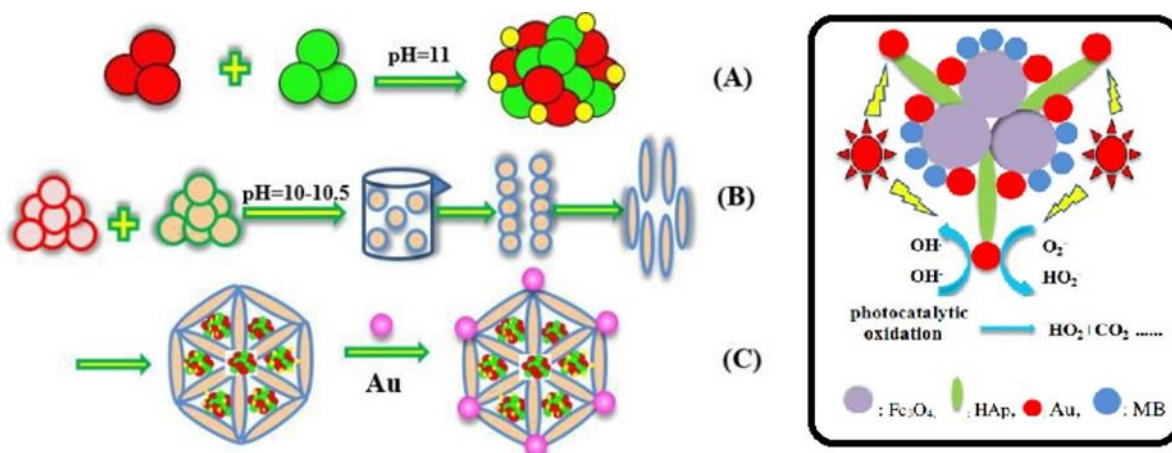


Figure 7. Synthetic procedure (A-C) and photocatalytic reaction of $\text{Fe}_3\text{O}_4/\text{HAp}/\text{Au}$ [74]

4.1 Hybrid Pd- Fe_3O_4 nanoparticles for various C-C coupling reactions

The Suzuki-Miyaura coupling, Mizoroki-Heck, and Sonogashira reactions are important reactions using Pd catalysts to produce C-C coupling reactions. Recently Pd- Fe_3O_4 NPs were applied in C-C coupling reactions [75-77].

$\text{FePd}-\text{Fe}_3\text{O}_4$ composites were synthesized in various Fe/Pd ratios as the synthetic procedure is illustrated in the **Figure 8**. Additionally, TEM image of the urchin-like $\text{FePd}-\text{Fe}_3\text{O}_4$ composite nanoparticles is depicted in the **Figure 8** [78].

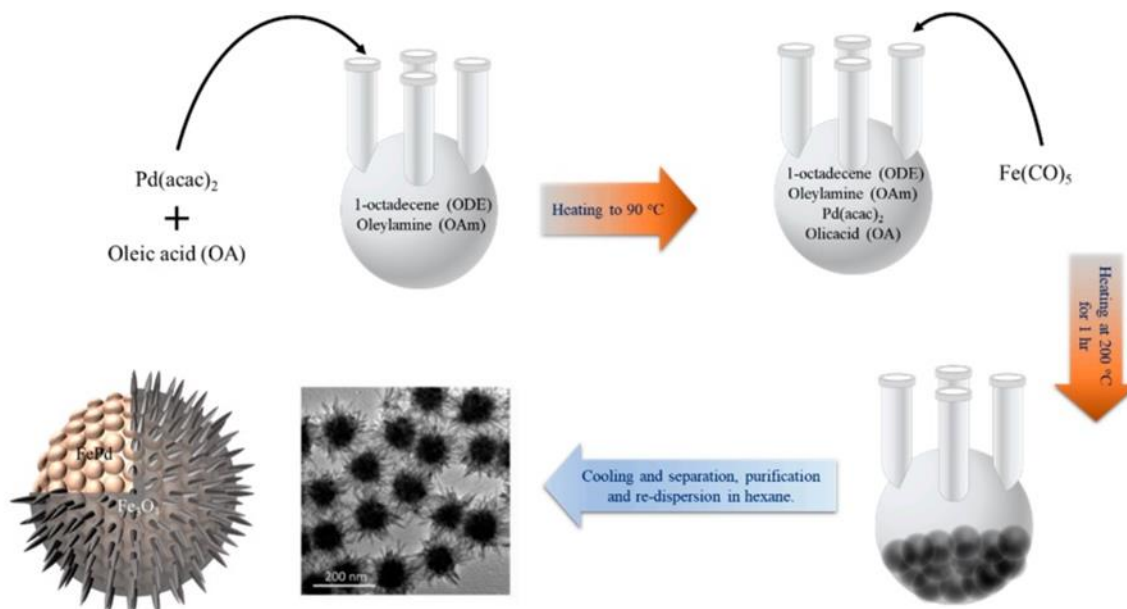


Figure 8. Synthetic procedure of urchin-like $\text{FePd}-\text{Fe}_3\text{O}_4$ [78]

A simple route based on time-dependent growth was performed to synthesize nanospheres Pd/ Fe_3O_4 (**Figure 9**) using $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ as the single iron resource, polyvinylpyrrolidone (PVP) as the capping

agent, and sodium acetate as the precipitation agent. To investigate the catalytic activity of the catalyst Heck reaction of iodobenzene and styrene was selected which is illustrated in **Scheme 28** [79, 80].

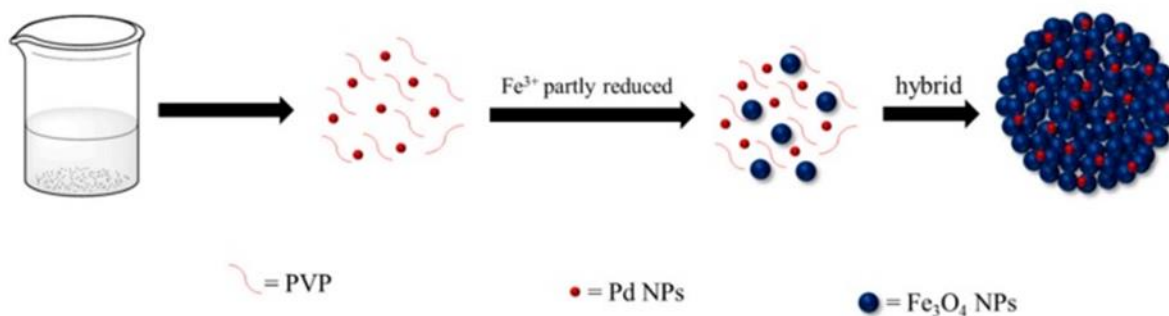
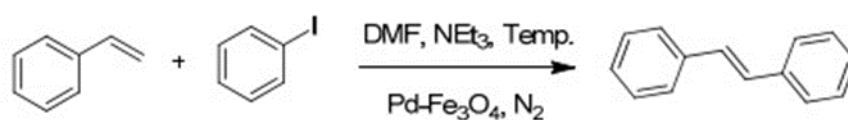


Figure 9. Synthetic procedure of Pd/Fe₃O₄ nanospheres [79, 80]



Scheme 28. Heck reaction using Pd/Fe₃O₄ nanospheres [79, 80]

Fe₃O₄@C-Pd catalyst synthesis was proceed via Stöber method in the synthesis of resin spheres composed of resorcinol-formaldehyde (RF) which were transformed to carbon spheres

(**Figure 10**). The catalytic efficiency of the synthetic nanocomposite was studied in the Suzuki coupling reactions of diverse aryl halides and aryl boronic acids [81-84].

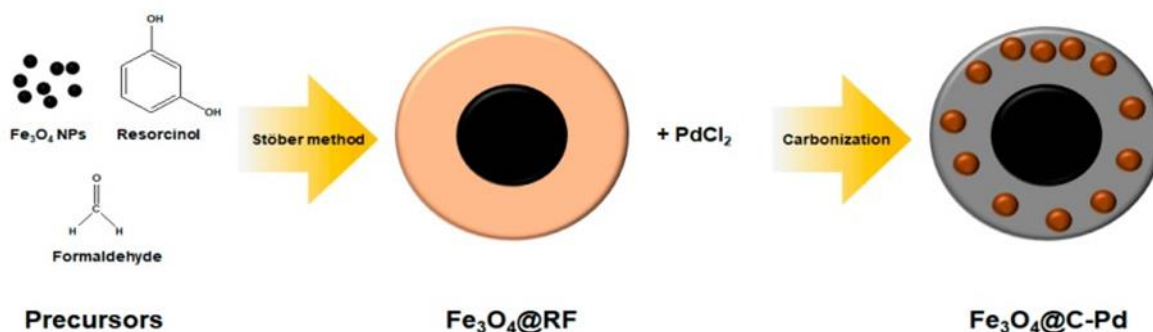
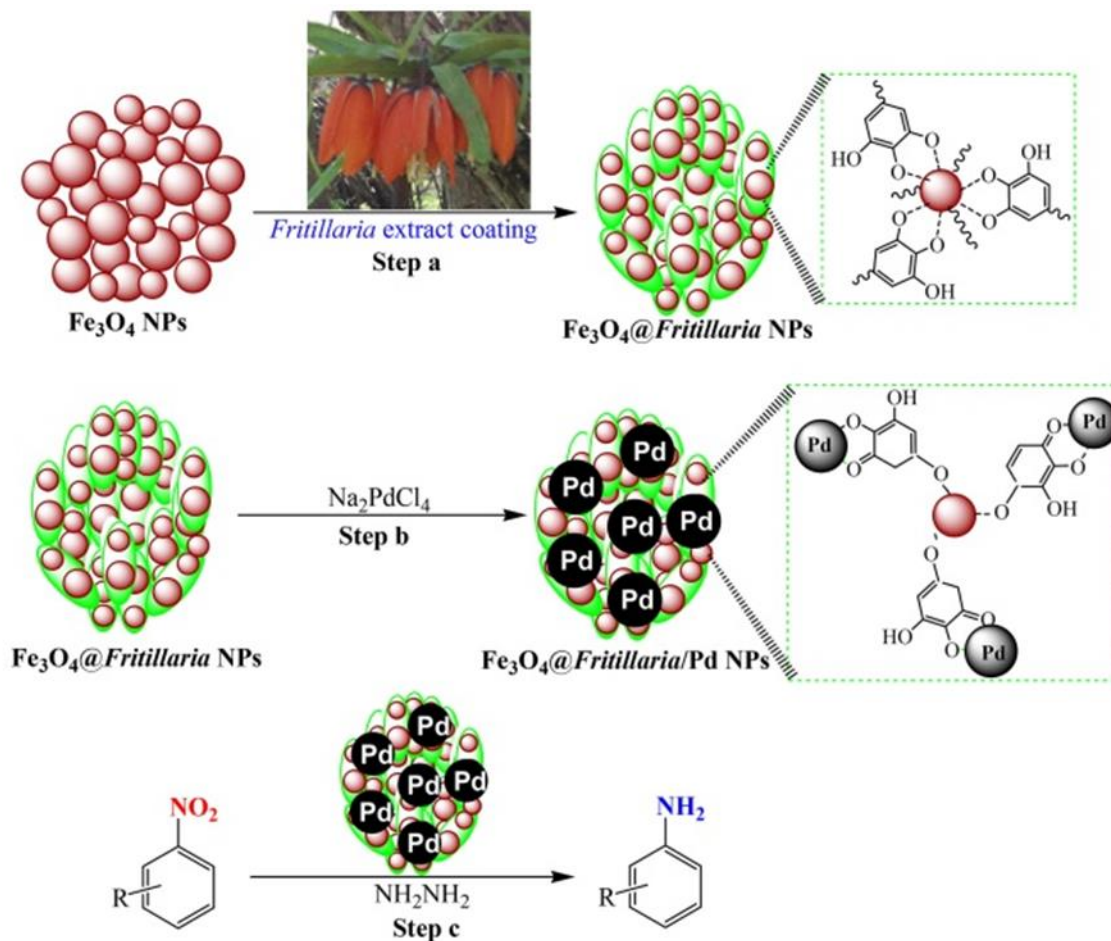


Figure 10. Fe₃O₄@C-Pd Catalyst preparation

4.2 Flower-Like organic capping agent of hybrid Fe₃O₄ NPs

Palladium nanoparticles fabricated magnetic Fe₃O₄ nanocomposite over *Fritillaria imperialis* flower extract synthesized to many uses such as as using as an efficient recyclable catalyst for the

reduction of nitroarenes. In this catalyst, hybrid magnetic nanocomposite Fe₃O₄ NPs are at core and Pd NPs are at outer shell. For the goal synthesis, Fe₃O₄ nanocomposite, Fe₃O₄@*Fritillaria* using the plant extract, and Fe₃O₄@*Fritillaria*/Pd NPs was prepared, respectively (**Scheme 29**) [85].



Scheme 29. Synthetic steps of $\text{Fe}_3\text{O}_4@$ Fritillaria/Pd to reduce nitroarenes [85]

5. Conclusion

Fe_3O_4 magnetic nanoparticles and their hybrids display capable applications in heterogeneous catalysis because of their ease of separation and good reusability. Preparation techniques of these nanocomposites are undergoing rapid development. In this report, we highlight the preparation of support materials to develop the quality of magnetically recoverable catalysts. Typical advancement on preparation of surface-modified MNPs was illustrated to obtain different type of Fe_3O_4 magnetic nanomaterials. Progressive types of Fe_3O_4 nanoparticles and their Hybrids as catalysts will be prepared in the future which will impress other type of known and unknown organic reactions.

Acknowledgment

The authors would like to acknowledge the management and principal of University of

Mazandaran, Damghan University, University of Baghdad and University of Mosul for their constant motivation and support.

Conflict of Interest

The author declares that there is no conflict of interest.

Orcid:

Heshmatollah Alinezhad

<https://www.orcid.org/0000-0002-7189-2961>

Parvin Hajiabbas Tabar Amiri

<https://www.orcid.org/0000-0001-9065-1779>

Raad Muslim Muhiebes

<https://www.orcid.org/0000-0002-4835-0873>

Yasser Fakri Mustafa

<https://www.orcid.org/0000-0002-0926-7428>

References

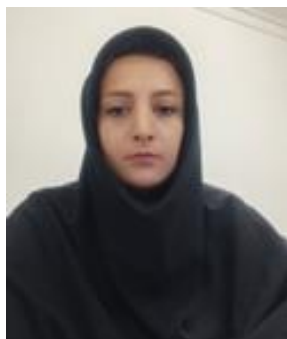
- [1]. Y. Dessie; S. Tadesse, *J. Chem. Rev.*, **2021**, *3*, 320-344. [[Crossref](#)], [[Publisher](#)]
- [2]. S. M. Abegunde, K. S. Idowu, A. O. Sulaimon, *J. Chem. Rev.*, **2020**, *2*, 103-113. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [3]. P. R. Fernandes; P. Patil; R. C. Shete, *J. Chem. Rev.*, **2022**, *4*, 25-39. [[Crossref](#)], [[Publisher](#)]
- [4]. F. Ajormal, F. Moradnia, S. T. Fardood, A. Ramazani, *J. Chem. Rev.*, *2*, **2020**, 90-102. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [5]. I. A. Abdalsamed; I. A. Amar; A. A. Sharif; M. A. Ghnim; A. A. farouj; J. A. Kawan, *J. Chem. Rev.*, **2022**, *4*, 67-80. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [6]. M. Sheykhani, L. Mamani, A. Ebrahimi, A. Heydari, *J. Mol. Catal. A: Chem.*, **2011**, *335*, 253-261. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [7]. A.R. Kiasat, S. Nazari, *J. Mol. Catal. A: Chem.*, **2012**, *365*, 80-86. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [8]. A.R. Kiasat, S. Nazari, *J. Incl. Phenom. Macrocycl. Chem.*, **2013**, *76*, 363-368. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [9]. A. Pfeifer, K. Zimmermann, C. Plank, *Pharm. Res.*, **2012**, *29*, 1161-1164. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [10]. M.Z. Kassaei, H. Masrouri, F. Movahedi, *Monatsh. Chem.*, **2010**, *141*, 317-322. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [11]. S. Nazari, S. Saadat, P. Kazemian Fard, M. Gorjizadeh, E. Rezaee Nezhad, M. Afshari, *Monatsh. Chem.*, **2013**, *144*, 1877-1882. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [12]. I.J. Bruce, T. Sen, *Langmuir*, **2005**, *21*, 7029-7035. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [13]. C. Alexiou, R. Jurgons, R. Schmid, A. Hilpert, C. Bergemann, F. Parak, H. Iro, *J. Magn. Magn. Mater.*, **2005**, *293*, 389-393. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [14]. J.L. Zhang, R.S. Srivastava, R.D.K. Misra, *Langmuir*, **2007**, *23*, 6342-6351. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [15]. Y.M. Huh, E.S. Lee, J.H. Lee, Y.W. Jun, P.H. Kim, C.O. Yun, J.H. Kim, J.S. Suh, J. Cheon, *Adv. Mater.*, **2007**, *19*, 3109-3112. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [16]. M.F. Kircher, U. Mahmood, R.S. King, R. Weissleder, L.A. Josephson, *Cancer Res.*, **2003**, *63*, 8122-8125. [[Google Scholar](#)], [[Publisher](#)]
- [17]. S. Rostamzadeh Mansour, N. Sohrabi-Gilani, P. Nejati, *Adv. J. Chem. A*, **2022**, *5*, 31-44. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [18]. S. Mousavi Ghahfarokhi, K. Helfi, M. Zargar Shoushtari, *Adv. J. Chem. A*, **2022**, *5*, 45-58. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [19]. A. Dehno Khalaji, P. Macheck, M. Jarosova, *Adv. J. Chem. A*, **2021**, *4*, 317-326. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [20]. H. Pardoe, P.R. Clark, T.G. Pierre, P. Moroz, S.K.A. Jones, *Magn. Reson. Imag.*, **2003**, *21*, 483-488. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [21]. E.W. Wong, M.J. Bronikowski, M.E. Hoenk, R.S. Kowalczyk, B.D. Hunt, *Chem. Mater.*, **2005**, *17*, 237-241. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [22]. M. Esmaeilpour, J. Javidi, F. Nowroozi Dodeji, H. Hassannezhad, *J. Iran. Chem. Soc.*, **2014**, *11*, 1703-1715. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [23]. R. Hudson, S. Ishikawa, C.J. Li, A. Moores, *Synlett*, **2013**, *24*, 1637-1642. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [24]. V. Polshettiwar, R.S. Varma, *Chem. Eur. J.*, **2009**, *15*, 1582-1586. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [25]. V. Polshettiwar, B. Baruwati, Varma, R.S. *Green Chem.*, **2009**, *11*, 127-131. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [26]. V. Polshettiwar, R.S. Varma, *Org. Biomol. Chem.*, **2009**, *7*, 37-40. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [27]. V. Polshettiwar, B. Baruwati, R.S. Varma, *Chem. Commun.*, **2009**, 1837-1839. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [28]. O. Gleeson, G.L. Davies, A. Peschiulli, R. Tekoriute, Y.K. Gun'ko, S. Connon, *J. Org. Biomol. Chem.*, **2011**, *9*, 7929-7940. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [29]. P.D. Stevens, J. Fan, H.M.R. Gardimalla, M. Yen, Y. Gao, *Org. Lett.*, **2005**, *7*, 2085-2088. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [30]. Z.L. Shen, Y.C. Lai, C.H.A. Wong, K.K.K. Goh, Y.S. Yang, H.L. Cheong, T.P. Loh, *Org. Lett.*, **2011**, *13*, 422-425. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [31]. Lv, G.; Mai, W.; Jin, R.; Gao, L. *Synlett*, **2008**, 1418-1422. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

- [32]. B.G. Wang, B.C. Ma, Q. Wang, W. Wang, *Adv. Synth. Catal.*, **2010**, *352*, 2923-2928. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [33]. Y. Hu, Z. Zhang, H. Zhang, L. Luo, S. Yao, *J. Solid State Electro Chem.*, **2012**, *16*, 857-867. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [34]. B. Mirhosseini-Eshkevari, M.A. Ghasemzadeh, J. Safaei-Ghomi, *Res. Chem. Intermed.*, **2015**, *41*, 7703-7714. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [35]. A. Mobinikhaledi, A. Khajeh-Amiri, *Reac. Kinet. Mech. Cat.*, **2014**, *112*, 131-145. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [36]. J. Safari, Z. Zarnegar, *J. Chem. Sci.*, **2013**, *125*, 835-841. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [37]. J. Safari, Z. Zarnegar, *RSC Adv.*, **2015**, *5*, 17738-17745. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [38]. A. Khalafi-Nezhad, M. Nourisefata, F. Panahi, *Org. Biomol. Chem.*, **2015**, *13*, 7772-7779. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [39]. A. Maleki, Z. Alirezvani, S. Maleki, *Catal. Commun.*, **2015**, *69*, 29-33. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [40]. A. Rostami, B. Atashkar, H. Gholami, *Catal. Commun.*, **2013**, *37*, 69-74. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [41]. M. Esmaeilpour, J. Javidi, F. Nowroozi Dodeji, *RSC Adv.*, **2015**, *5*, 308-315. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [42]. H. Eshghi, A. Khojastehnezhad, F. Moeinpour, S. Rezaeian, M. Bakavoli, M. Teymouri, A. Rostami, K. Haghbeen, *Tetrahedron*, **2015**, *71*, 436-444. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [43]. A. Khalafi-Nezhad, F. Panahi, R. Yousefi, S. Sarrafi, Y. Gholamalipour, *J. Iran. Chem. Soc.*, **2014**, *11*, 1311-1319 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [44]. F. Rastegari, I. Mohammadpoor-Baltork, A.R. Khosropour, S. Tangestaninejad, V. Mirkhani, M. Moghadam, *RSC Adv.*, **2015**, *5*, 15274-15282. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [45]. S. Nazari, S. Saadat, P. Kazemian Fard, M. Gorjizadeh, E. Rezaee Nezhad, M. Afshari, *Monatsh. Chem.*, **2013**, *144*, 1877-1882. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [46]. Z. Zarnegar, J. Safari, *J. Nanopart. Res.*, **2014**, *16*, 2509. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [47]. J. Safari, Z. Zarnegar, *C. R. Chim.*, **2013**, *16*, 920-928. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [48]. J. Safari, Z. Zarnegar, *RSC Adv.*, **2013**, *3*, 26094-26101. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [49]. M. Jafarzadeh, E. Soleimani, H. Sepahvand, R. Adnan, *RSC Adv.*, **2015**, *5*, 42744-42753, [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [50]. S.M. Sadeghzadeh, F. Daneshfar, M. Malekzadehc, *Chin. J. Chem.*, **2014**, *32*, 349-355. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [51]. S.M. Sadeghzadeh, *RSC Adv.*, **2014**, *4*, 43315-43320. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [52]. A.A. Jafari, H. Mahmoudi, H. Firouzabadi; *RSC Adv.*, **2015**, *5*, 107474-107481. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [53]. M. Ghavami, M. Koochi, M. Zaman Kassae, *J. Chem. Sci.*, **2013**, *125*, 1347-1357. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [54]. M. Safaieea, M.A. Zolfigol, F. Afsharnadery, S. Baghery, *RSC Adv.*, **2015**, *5*, 102340-102349. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [55]. M. Tajbakhsh, M. Farhang, R. Hosseinzadeh, Y. Sarrafi, *RSC Adv.*, **2014**, *4*, 23116-23124. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [56]. J. Davarpanah, A.R. Kiasat, S. Noorzadeh, M. Ghahremani, *J. Mol. Catal. A: Chem.*, **2013**, *376*, 78-89. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [57]. R. Tayebbe, M.M. Amini, H. Rostamian, A. Aliakbari, *Dalton Trans.*, **2014**, *43*, 1550-1563. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [58]. A. Mobinikhaledi, N. Foroughifar, A. Khajeh-Amiri, *Reac. Kinet. Mech. Cat.*, **2016**, *117*, 59-75. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [59]. A. Fallah-Shojaei, K. Tabatabaeian, F. Shirini, S.Z. Hejazi; *RSC Adv.*, **2014**, *4*, 9509-9516. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [60]. R. Tayebbe, M.M. Amini, H. Rostamian, A. Aliakbari, *Dalton Trans.*, **2014**, *43*, 1550-1563. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [61]. S. Rostamnia, B. Zeynizadeh, E. Doustkhah, A. Baghban, Kh. Ojaghi Aghbash, *Catal. Commun.*, **2015**, *68*, 77-83. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [62]. D. Saberi, S. Cheraghi, S. Mahdudi, J. Akbari, A. Heydari, *Tetrahedron Lett.*, **2013**, *54*, 6403-6406. [[Crossref](#)], [[Google Scholar](#)],

- [[Publisher](#)]
 [63]. 55. K. Azizi, A. Heydari, *RSC Adv.*, **2014**, *4*, 6508-6512. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [64]. H. Firouzabadi, N. Iranpoor, M. Gholinejad, S. Akbaria, N. Jeddib, *RSC Adv.*, **2014**, *4*, 17060-17070. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [65]. Y.C. Pan, Y.Y. Liu, G.F. Zeng, L. Zhao, Z.P. Lai, *Chem. Commun.*, **2011**, *47*, 2071-2073. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [66]. F. Pang, M. He, J. Ge, *Chem. Eur. J.*, **2015**, *21*, 1-10. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [67]. F. Zamani, E. Izadi, *Catal. Commun.*, **2013**, *42*, 104-108. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [68]. C.G.S. Lima, S. Silva, R.H.G. Aalves, E.R. Leite, R.S. Schwab, A.G. CorrTa, M.W. Paix, *Chem Cat. Chem.*, **2014**, *6*, 3455-3463. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [69]. A. Khazaei, F. Gholami, V. Khakyzadeh, A.R. Moosavi-Zare, J. Afsar, *RSC Adv.*, **2015**, *5*, 14305-14310. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [70]. Y. Ruzmanova, M. Stoller, A. Chianese, *Chem. Engin. Transactions*, **2013**, *32*, 2233-2238. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [71]. A. Amoozadeh, S. Golian, S. Rahmani, *RSC Adv.*, **2015**, *5*, 45974-45982. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [72]. M. Adeli and Z. Zarnegar, *J. Appl. Polym. Sci.*, **2009**, *113*, 2072-2080. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [73]. Z. Zarnegar, J. Safari, *New J. Chem.*, **2014**, *38*, 4555-4565. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [74]. R. Wu, X. Ji, D. Xia, H. Xiong, J. Lu, *research square*, **2021**, 1-10. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [75]. Y. Jang, J. Chung, S. Kim, S.W. Jun, B.H. Kim, D.W. Lee, B.M. Kim, T. Hyeon, *Phys. Chem. Chem. Phys.*, **2011**, *13*, 2512-2516. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [76]. M. Zhu, G. Diao, *J. Phys. Chem. C*, **2011**, *115*, 24743-24749. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [77]. L. Zhou, C. Gao, W. Xu, *Langmuir*, **2010**, *26*, 11217-11225. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [78]. Y. Hayashi, *Chem. Sci.*, **2016**, *7*, 866-880. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [79]. M. Zhu, G. Diao, *J. Phys. Chem. C*, **2011**, *115*, 18923-18934. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [80]. H.Q. Wang, X. Wei, K.X. Wang, J.S. Chen, *Dalt. Trans*, **2012**, *41*, 3204-3208. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [81]. A.B. Fuertes, P. Valle-Vigón, M. Sevilla, *Chem. Commun.*, **2012**, *48*, 6124-6126. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [82]. T. Yang, J. Liu, Y. Zheng, M.J. Monteiro, S.Z. Qiao, *Chem. A Eur. J.*, **2013**, *19*, 6942-6945. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [83]. R. Liu, F. Qu, Y. Guo, N. Yao, R.D. Priestley, *Chem. Commun.*, **2014**, *50*, 478-480. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [84]. C. Sun, K. Sun, S. Tang, *Mater. Chem. Phys.*, **2018**, *207*, 181-185. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
 [85]. H. Veisi, B. Karmakar, T. Tamoradi, *Sci. Rep.*, **2021**, *11*, 4515-4530. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]



Parvin Hajiabbas Tabar Amiri: She was born in 1984 in Babol, Mazandaran, Iran. She received her B.Sc. degree in chemistry from Tehran University, Tehran, Iran in 2006, her M.Sc. degree in organic chemistry from Tehran University, Tehran, Iran, in 2010 and her Ph.D degree in organic chemistry at Alzahra University, Tehran, Iran in 2015. She has various teaching experiences, such as Organic Chemistry, General chemistry, Spectrometric analysis and etc. She has many published work in reputable international publishing houses and reviewer in many international journals. She is presently enduring her researches in the synthesis of organic compounds, heterocycles, natural products and medicinal compounds.



Sahar Mohseni Tavakkoli: She was born in 1983 in Ghaemshahr, Mazandaran, Iran. She received her B.Sc. degree in chemistry from University of Mazandaran, Babolsar, Iran in 2007, her M.Sc. degree in organic chemistry from University of Mazandaran, Babolsar, Iran, in 2010 and her Ph.D degree in organic chemistry from University of Mazandaran, Babolsar, Iran in 2014. She is presently working in fertilizer production company.



Raed Muslim Muhibes: He was born in Baghdad, Iraq, in 1978. He received his B.Sc. in Chemistry from the College of Science at the University of Baghdad in 2007. Also, he acquired the M.Sc. and Ph.D. degrees in Organic Chemistry from the College of Chemistry/College of Science / Southern Fdrution University of Russian, Baghdad, Iraq, in 2014 and 2021, respectively. He had various teaching experiences, such as Organic Chemistry, Analytical Chemistry, Biochemistry. Also, he is an editorial member of several documented journals, such as, Journal of Medicinal and Chemical Sciences, Eurasian Chemical Communications, Chemical Methodology and Asian Journal of Green Chemistry.



Yasser Fakri Mustafa: He was born in Mosul, Iraq, in 1976. He received his B.Sc. in Pharmacy from the College of Pharmacy at the University of Mosul in 1999. Also, he acquired the M.Sc. and Ph.D. degrees in Pharmacy/Pharmaceutical Chemistry from the College of Pharmacy/University of Mosul, Mosul, Iraq, in 2005 and 2017, respectively. He had various teaching experiences, such as organic pharmaceutical chemistry, inorganic pharmaceutical chemistry, chemistry of natural products, chemotaxonomy, and heterocyclic compounds. Also, he is an editorial member of several documented journals, such as the Iraqi Journal of Pharmacy, Mosul Journal of Nursing, Journal of Medicinal and Chemical Sciences, Eurasian Chemical Communications, and the International Journal of Pharmacy and Chemistry.