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PII: S1350-4177(16)30186-9
DOI: http://dx.doi.org/10.1016/j.ultsonch.2016.05.043
Reference: ULTSON 3253

To appear in: *Ultrasonics Sonochemistry*

Received Date: 8 April 2016
Revised Date: 25 May 2016
Accepted Date: 26 May 2016

Please cite this article as: H. Naeimi, R. Shaabani, Ultrasound promoted facile one pot synthesis of triazole derivatives catalyzed by functionalized graphene oxide Cu(I) complex under mild conditions, *Ultrasonics Sonochemistry* (2016), doi: http://dx.doi.org/10.1016/j.ultsonch.2016.05.043

Ultrasound promoted facile one pot synthesis of triazole derivatives catalyzed by functionalized graphene oxide Cu(I) complex under mild conditions

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Abstract

A facile one pot three component reaction of alkyl halides, sodium azide with terminal alkynes can be catalyzed by functionalized graphene oxide copper (I) complex under ultrasonic irradiation at room temperature. In this protocol, the 1,4-disubstituted 1,2,3-triazoles were afforded as target pure products in excellent yields and short reaction times. The prepared catalyst has been characterized by Fourier transform infrared spectroscopy (FT-IR), X-ray diffraction spectroscopy (XRD), Energy Dispersive X-ray (EDX) and field emission scanning electron microscopy (FE-SEM) techniques. Also, the catalyst is chemoselective and stable and can be reused several times without any appreciable loss of its catalytic activity.

Keywords: Ultrasound, 1,2,3-Triazole, Graphene oxide, Ultrasound, One pot, Three component.

Introduction

The triazole rings has been widely used in pharmaceuticals, agro chemicals, dyes, photographic materials, corrosion inhibition [1]. 1,2,3-Triazoles are also associated with a wide range of biological properties such as antiviral (I) [2], antiepileptic, antiallergic [3], anticancer (II) [4-6] and anti HIV (III, IV) [7] (Fig. 1).

<Figure 1>

These heterocyclic compounds were readily prepared from Cu (I)-catalyzed azide–alkyne 1,3-dipolar cycloaddition (CuAAC) [8,9]. The required copper (I) catalysts are usually prepared by in situ reduction of copper (II) salts with ascorbate [10,11], or by comproportionation of copper (0) and copper (II) [12,13]. In recent studies, the CuAAC has been proven to be accelerated by Cu(I) species supported by nitrogen [14], sulfur [15], TiO_2-nanotube/Ti plates loaded Cu_2O nanoparticles [16], Copper/Graphene/Clay Nanohybrid [17], chitosan-stabilised copper–iron oxide nanocomposite [18] and polydentate ligands [19], since those serve both to protect the copper (I) center from oxidation or disproportionation and to enhance its catalytic activity. Moreover, a number of heterogeneous catalysts for this reaction are also reported such as: magnetic starch immobilized by copper ions [20], copper (I) confined in interlayer space of montmorillonite [21] and copper (I) iodide nanoparticles on polyaniline [22].

Although organic azides are generally safe compounds, those of low molecular weight can be unstable and, therefore, difficult to handle [23]. Thus, a method that avoids isolation of organic azides is desirable. In situ generation of organic azides from suitable precursors followed by addition of alkyne in one-pot, to form the corresponding 1,2,3-triazole would avoid the difficulties associated with the explosive nature of azides. Already, the one-pot synthesis of 1,2,3-triazoles from alkyl halides, alkynes and sodium azides in the presence of copper (I) as a catalyst have been reported [24].

Graphene a single two-dimensional (2D) large of carbon atoms, has attached much attention in recent years [25]. Graphene and graphene oxide (GO) have fantastic physical, optical, and mechanical properties [26, 27]. Recently, graphene oxide (GO), the precursor of graphene, which has a wide range of oxygen functional groups had been directly used as a catalyst for many reactions [28].

Ultrasound-assisted organic synthesis, as a synthetic approach, is a powerful technique that is used to accelerate organic reactions. The notable features of the ultrasound approach are enhanced reaction rates, formation of pure products in high yields, and easier manipulation [29, 30]. Ultrasound has been recognized as an important technique for green and sustainable synthetic processes [31-33].

In 1984, Priebe [34] described the synthesis of organic azides from the corresponding activated primary halides and aqueous sodium azide under ultrasonic irradiation. Also, the acceleration of the reaction rate of Huisgen reaction by ultrasonic irradiation has already been reported by other groups [35-37].

In continuation of our work on going toward usage of ultrasonic irradiation in organic synthesis [38, 39], we hope to report a simple synthetic sonochemical preparation of 1-H-1,2,3-triazoles in the presence of Cu(I) functionalized graphene oxide as heterogeneous catalyst at room temperature.

2. Experimental

2.1. Materials

High-purity chemicals were purchased from Merck, Fluka, and Aldrich. All materials were of commercial reagent grade. Alkyl halides and solvents were purified by using of standard procedures.

2.2. Apparatus

IR spectra were recorded as KBr pellets on a Perkin–Elmer 781 spectrophotometer and an Impact 400 Nicolet FT-IR spectrophotometer. ^{1}H NMR and ^{13}C NMR spectra were recorded in DMSO-d_6 or $CDCl_3$ as solvents on a Bruker DRX-400 spectrometer, with tetramethyl silane as internal reference. A Bandelin ultrasonic HD 3200 with 6 mm diameter model KE 76 probe was used to generate ultrasonic irradiation and homogenize the reaction mixture. The piezoelectric crystals in this kind of probe normally work at approximately 700 kHz; by use of appropriate clamps. However, the output frequency of piezoelectric crystals was controlled and reduced to 20 kHz in the reaction mixture. X-ray diffraction patterns of samples were taken on a Philips Xpert X-ray powder diffraction diffractometer (CuK, radiation, k=0.154056 nm). FE-SEM and elemental analysis were carried out using a Jeol SEM instrument (model- VESCAN) combined with an INCA instrument for energy dispersive X-ray scanning electron microscopy (EDX-SEM), Field emission scanning electron microscopy (FE SEM) images were obtained by HITACHI S-4160. Melting points obtained with a Thermo scientific 9300 melting point apparatus. Determination of the substrate purity and monitoring of reactions were accomplished by use of thin-layer chromatography (TLC) on Polygram SILG/UV 254 silica gel plates (Merck).

2.3. General procedure for the synthesis of functionalized graphene oxide Cu(I) complex (GO-NH-IA-Cu(I))

2.3.1. Synthesis of graphene oxide (GO)

Graphene oxide was prepared using a modification of Hummers and Offeman's method [34]. Briefly in a typical reaction, 2 g graphite, 1 g $NaNO_3$, and 46 mL H_2SO_4 were stirred together in an ice bath. $KMnO_4$ (6 g) was slowly added while stirring, and the rate of addition was controlled to prevent the mixture temperature from exceeding 5^{o}C. The mixture was then transferred to a 35 ^{o}C water bath and stirred for about 30 min, forming a thick paste.

Subsequently, 100 mL de-ionized water was added gradually and the temperature was raised to 98 °C. The mixture was further treated with 500 mL deionized water and 15 mL 30% H_2O_2 solution. The warm solution was then filtered and dried at 65 °C under vacuum. Finally, the precipitate was dispersed in water by sonication.

2.3.2. Synthesis of GO–COCl

In this step, GO (0.5 g) was suspended in $SOCl_2$ (30 mL) and 10 mL of DMF was added and refluxed at 70 °C for 24 h. The resultant solution was filtered and washed with anhydrous tetrahydrofuran (THF) and dried under vacuum, the GO-COCl was obtained.

2.3.3. Synthesis of amino-functionalized grapheme oxide (GO-CO-NH_2)

The GO–COCl (0.4 g) was suspended in 1,7-heptandiamine and 25 mL DMF was added and refluxed at 70 ° C for 24 h. The resultant solution was filtered and washed with ethanol to ensure that the excess diamine was completely removed. Finally, the products were dried at 70 °C under vacuum.

2.3.4. Synthesis of functionalized graphene oxide with isotoic anhydride (GO-CO-NH-IA)

In continuation of the catalyst preparation, GO-CO-NH_2 (0.36 g) and isotoic anhydride (0.36 g) was suspended in 30 mL ethanol was added and refluxed at 60 °C for 24 h. The resultant solution was filtered and washed with ethanol to ensure that the excess isotoic anhydride was completely removed. Finally, the products were dried at 70 °C under vacuum.

2.3.5. Synthesis of functionalized graphene oxide with copper iodide complex (GO-CO-NH-IA-Cu (I))

In the final step, the GO-CO-NH-IA (0.35 g) and copper iodide (0.35 g) was suspended in 30 mL acetonitrile was added and refluxed at 60 ^{o}C for 18 h. The resultant solution was filtered and washed with acetonitrile to ensure that the excess copper iodide was completely removed. Finally, the products were dried at 70 ^{o}C under vacuum, the pure complex was obtained.

2.4. A typical procedure for the sonication synthesis of 1,2,3-triazoles

A mixture of alkyne (1mmol), alkyl halide (1 mmol), NaN_3 (1.2 mmol) and functionalized graphene oxide Cu (I) complex (0.005 g) as a catalyst were added to a mixture of water and EtOH (1:1) (6 mL) as solvent and the reaction mixture was soncated in ultrasonic apparatus with 70 Watt power. The progress of the reaction was monitored by TLC. After completion of the reaction, the reaction mixture was filtered through celite and the isolated catalyst was washed three times with ethanol (3× 10 mL). The organic layer was separated and dried by rotary evaporator until the solid product precipitated. In order to further purification, recrystallization of the product was performed at 5:1 EtOAc:MeOH to yield the pure desired products. The products were characterized by ^{1}H NMR, ^{13}C NMR, FT-IR and melting points and the spectral data of synthesized compounds were compared with authentic samples as followed;

1-Benzyl-4-phenyl-1H-1,2,3-triazole; (Table 5, entry 1); White solid, m.p = 125-127 ^{o}C (Lit. [41]. 128-130 ^{o}C); IR (KBr) ν (cm^{-1}): 3139 (C=C-H), 2924 (-C-H), 1607 (C=C), 1456, 1353 (C-N), 1218, 1073, 1046; ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 5.58 (s, 2H, CH_2), 7.32 (m, 3H, $H_{aromatic}$), 7.40 (m, 5H, $H_{aromatic}$), 7.67 (s, 1H, $H_{triazole}$), 7.80 (d, *J*=8.0 Hz, 2H, $H_{aromatic}$); ^{13}C NMR ($CDCl_3$, 100 MHz) δ (ppm): 54.21, 119.57, 125.71, 128.06, 128.17, 128.78, 128.82, 129.16, 130.58, 134.74, 148.22.

4-Bromobenzyl-4-phenyl-1H-1,2,3-triazole; (Table 5, entry 2); Colorless solid, m.p = 148-152 ^{o}C (Lit. [41]. 151-152 ^{o}C); IR (KBr) ν (cm^{-1}): 3123 (C=C-H), 2924 (-C-H), 2850, 1623 (C=C$_{aromatic}$), 1482, 1462 (CH$_2$, bending), 1352 (C-N, stretching), 1072, 1017, 761 (C-Br), 694; ^{1}H NMR (DMSO-d$_6$, 400 MHz) δ (ppm): 5.67 (s, 2H, CH$_2$), 7.35-7.38 (m, 5H, H$_{aromatic}$), 7.40-7.58 (m, 2H, H$_{aromatic}$), 7.88 (s, 2H, H$_{aromatic}$), 8.39 (s, 1H, H$_{triazole}$); ^{13}C NMR (DMSO, 100 MHz) δ (ppm): 52.79, 121.95, 122.09, 125.67, 128.37, 129.34, 130.62, 131.09, 132.17, 135.81, 147.21.

1-(3-Chlorobenzyl)-4-phenyl-1H-1,2,3-triazole; (Table 4, entry 3); Colorless solid, m.p = 88-91 ^{o}C (Lit. [42]. 87-89 ^{o}C); IR (KBr) ν (cm^{-1}): 3082 (C=C-H), 2925 (-C-H), 1725, 1574 (C=C$_{aromatic}$), 1465 (CH$_2$, bending), 1432, 1344 (C-N, stretching), 1221, 1076, 756 (C-Cl), 692; ^{1}H NMR (Acetone-d$_6$, 400 MHz) δ (ppm): 5.71 (s, 2H, CH$_2$), 7.41-7.44 (m, 7H, H$_{aromatic}$), 7.89 (s, 2H, H$_{aromatic}$), 8.44 (s,1H, H$_{triazole}$); ^{13}C NMR (DMSO-d$_6$, 100 MHz) δ (ppm): 52.76, 122.15, 125.68, 127.08, 128.33, 128.62, 129.33, 131.14, 131.49, 133.85, 138.85, 147.52.

1-(2-Chlorobenzyl)-4-phenyl-1H-1,2,3-triazole; (Table 5, entry 4); Colorless solid, m.p = 93-95 ^{o}C (Lit. [43] 96-97 ^{o}C); IR (KBr) ν(cm^{-1}): 3123 (C=C-H), 2925 (-C-H), 1572 (C=C$_{aromatic}$), 1466, 1438 (CH$_2$, bending), 1444, 1359 (C-N, stretching), 1272, 1221, 1126, 1079, 1042, 977, 753 (C-Cl), 692; ^{1}H NMR (CDCl$_3$, 400 MHz) δ (ppm): 5.85 (s, 2H, CH$_2$), 7.06 (d, *J*=8.0 Hz, 1H, H $_{aromatic}$), 7.22-7.27 (t, 1H), 7.41-7.45 (m, 3H), 7.47-7.49 (m, 3H), 8.24 (d, *J*=8.0 Hz, 2H, H$_{aromatic}$, H$_{triazole}$); ^{13}C NMR (CDCl$_3$, 100 MHz) δ (ppm): 51.69, 121.37, 126.24, 127.39, 128.23, 128.67, 129.07, 129.67, 130.185, 131.59, 132.6, 132.86, 148.01.

1-(2-Chloro-6-fluorobenzyl)-4-phenyl-1H-1,2,3-triazole; (Table 5, entry 5); Colorless solid, m.p = 102-105 ^{o}C (Lit.[44] 106-108 ^{o}C); IR (KBr) ν (cm^{-1}): 3128 (C=C-H), 2924 (-C-H), 1643, 1606 (C=C$_{\text{aromatic}}$), 1577, 1457(C-F), 1353 (C-N, stretching), 762 (C-Cl), 693; ^{1}H NMR (DMSO-d$_6$, 400 MHz) δ (ppm): 5.86 (s, 2H, CH$_2$), 7.33-7.62 (m, 7H, H$_{\text{aromatic}}$), 8.08 (s, 2H, H$_{\text{aromatic}}$, H$_{\text{triazole}}$); ^{13}C NMR (CDCl$_3$, 100 MHz) δ (ppm): 49.32, 114.95, 116.04, 118.65, 125.40, 127.10, 127.59, 128.99, 130.07, 133.02, 133.54, 135.08, 143.01, 152.82.

1-(2,4-Dinitrobenzyl)-4-phenyl-1H-1,2,3-triazole; (Table 5, entry 6); Pale yellow solid, m.p= 211-214 °C (Lit.[44] 214-215 °C); IR (KBr) ν (cm^{-1}): 3124 (C=C-H), 1610 (C=C$_{\text{aromatic}}$), 1535 and 1348 (-NO$_2$), 1463 (CH$_2$, stretching), 1402, 1205, 1152, 1072; ^{1}H NMR (Acetone-d$_6$, 400 MHz) δ (ppm): 6.16 (s, 2H, CH$_2$), 7.2-7.36 (m, 2H, H$_{\text{aromatic}}$), 7.43-7.47 (t, *J*=7.2 Hz, 2H, H$_{\text{aromatic}}$), 7.84 (d, *J*=8.0 Hz, 2H, H$_{\text{aromatic}}$), 8.53(d, *J*=12.0 Hz, 1H, H$_{\text{triazole}}$), 8.64(s, 1H, H$_{\text{aromatic}}$), 8.84(s, 1H, H$_{\text{aromatic}}$); ^{13}C NMR (CDCl$_3$, 100 MHz) d (ppm): 50.47, 122.57, 125.40, 128.55, 129.02, 129.92, 131.02, 132.07, 138.34, 143.39, 146.18, 147.51.

1-Benzyl-4-(4-methylphenyl)-1H-1,2,3-triazol; (Table 5, entry 7); Pale yellow solid, m.p =150-152 °C (Lit.[45] 150 °C); IR (KBr) ν (cm^{-1}): 3141 (C=C-H), 2921 (-C-H), 1605 (C=C$_{\text{aromatic}}$), 1496, 1455, 1350 (C-N, stretching), 1221, 1006; ^{1}H NMR (CDCl$_3$, 400 MHz) δ (ppm): 2.159 (s, 3H, CH$_3$), 5.36 (s, 2H, CH$_2$), 7.17-7.47(m, 8H, H$_{\text{aromatic}}$), 7.88 (s, 2H, H$_{\text{aromatic}}$, H$_{\text{triazole}}$).

1-(4-Bromobenzyl)-4-(4-methylphenyl)-1H-1,2,3-triazole; (Table 5, entry 8); Pale yellow solid, m.p = 201–203 °C (Lit.[44] 202-204 °C); IR (KBr) ν (cm^{-1}): 3029 (C=C-H), 1623 (C=C$_{\text{aromatic}}$), 1592, 1521, 1487 (CH$_3$), 1442, 1341 (C-N, stretching), 1224, 1071, 1010, 824(C-Br), 741. ^{1}H NMR (Acetone-d$_6$, 400 MHz) δ (ppm): 2.33 (s, 3H, CH$_3$), 5 (d, *J*=16.0 Hz 1H), 5.2 (d, 1H), 6.82(d, *J*=8.0 Hz, 2H, H$_{\text{aromatic}}$), 7.01-7.03(s, 2H, H$_{\text{aromatic}}$), 7.18-7.23(m, 5H, H$_{\text{aromatic}}$, H$_{\text{triazole}}$); ^{13}C NMR (CDCl$_3$, 100 MHz) δ (ppm): 21.34, 52.02, 119.37, 123.02, 125.67, 126.19, 129.65, 129.76, 131.87, 139.26, 140.02, 148.16.

1-methyl-4-phenyl-1H-1,2,3-triazole; (Table 5, entry 9); Pale yellow solid m.p= 112-115 ^{o}C (Lit.[46] 111-113^{o}C); IR (KBr) ν (cm^{-1}): 2925 (C=C-H), 1609 (C=C$_{aromatic}$), 1449(CH$_3$), 1221 (C-N, stretching), 1237 (C-C), 1190, 1078; ^{1}H NMR (Acetone-d$_6$, 400 MHz) δ (ppm): 4.13(s, 3H, CH$_3$), 7.29-7.8 (m, 5H, H$_{triazole}$), 8.26 (s, 1H).

1-(4-Nitrobenzyl)-4-phenyl-1H-1,2,3-triazole; (Table 5, entry 10); Pale yellow solid, m.p = 140–142 ^{o}C (Lit.[41]. 140-141 ^{o}C); IR (KBr) ν (cm^{-1}): 3081 (C=C-H), 1604 (C=C), 1348 and 1518 (-NO$_2$), 1466 (-CH$_2$, bending), 1220 (C-N), 1109, 1077, 1044; ^{1}H NMR (DMSO-d$_6$, 400 MHz) δ (ppm): 5.702 (s, 2H, CH$_2$), 7.36-7.43 (m, 5H, H$_{aromatic}$), 7.76-7.82 (m, 3H, H$_{aromatic}$, H$_{triazole}$), 8.24(s, 2H, H$_{aromatic}$); ^{13}C NMR (CDCl$_3$, 100 MHz) δ (ppm): 53.16, 119.82, 124.31, 125.74, 128.56, 128.93, 130.11, 141.82, 148.03, 148.66.

1-(4-Nitrobenzyl)-4-(4-methylphenyl)-1H-1,2,3-triazole; (Table 5, entry 11); Green solid, m.p = 242–245 ^{o}C (Lit.[44] 242-243); IR (KBr) ν (cm^{-1}): 2924 (C=C-H), 1607 (C=C), 1346 and 1522(-NO$_2$), 1446(CH$_3$), 1220 (C-N); ^{1}H NMR (CDCl$_3$, 400 MHz) δ (ppm): 2.24 (s, 3H, CH3), 4.8 (s, 1H), 5.10 (s, 1H), 6.96 (s, 4H, H$_{aromatic}$), 7.24 (s, 3H, H$_{aromatic}$, H$_{triazole}$), 7.85 (s, 2H, H$_{aromatic}$).

1-Benzyl-4-propyl-1H-1,2,3-triazole; (Table 5, entry 12); green oil(Lit.[43, 45]); IR (KBr) ν (cm^{-1}): 2925 (C=C-H), 1626 (C=C$_{aromatic}$), 1449 (CH$_3$), 1237 (C-N, stretching), 1237 (C-C), 1158, 1084; ^{1}H NMR (CDCl$_3$, 400 MHz) δ (ppm): 0.95 (d, 3H, CH$_3$), 1.26 (s, 2H, -CH$_2$), 2.26 (s, 2H, -CH$_2$), 5.7 (s, 2H, -CH$_2$), 7.27-7.56 (m, 6H, H$_{aromatic}$, H$_{triazole}$); ^{13}C NMR (CDCl$_3$, 100 MHz) δ (ppm): 13.69, 22.01, 27.33, 53.92, 120.54, 127.83, 128.19, 128.75, 135.03, 150.09.

1-Cinnamyl-4-phenyl-1H-1,2,3-triazole; (Table 5, entry 13); Pale yellow solid, m.p= 128-130˚C (Lit.[47] 134 ^{o}C); IR (KBr) ν (cm^{-1}): 3130, 3028, 1606 (C=C$_{aromatic}$), 1461, 1074, 977, 760; ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 5.25 (d, *J*=4.0 Hz, 2H), 6.57-6.59 (m, 1H), 6.61 (d, *J*=4.0 Hz, 1H), 7.3-7.43 (m, 8H), 7.8(d, *J*=7.2 Hz, 2H), 8.41 (s, 1H).

3. Results and discussion

3.1 Preparation and characterization of the catalyst

A synthetic strategy of functionalized graphene oxide is shown in the Scheme 1. At first, graphene oxide was prepared according to the modified Hummer's method. The obtained GO was treated with thionyl chloride in DMF at reflux temperature for 24 hours to generate GO–COCl and subsequently reacted 1,7-heptandiamin to yield amino-modified graphene oxide (GO-CO-NH_2). The obtained amino-modified graphene oxide were then treated with isotoic anhydride in ethanol at reflux temperature for 24 hours to generate (GO-CO-NH-IA) Finally, the GO-CO-NH-IA was treated with CuI in acetonitrile at reflux temperature for 18 hours. The catalyst was characterized using various methods.

<Scheme 1>

Fig. 2 shows the FT-IR spectra of GO, GO–COCl, GO-NH2, GO-NH-IA. In the FT-IR spectrum of GO the peaks at 3349, 1719, 1580, 1064 cm^{-1} correspond to the O–H, C=O, C=C and C–O stretching vibration. In the FT-IR spectrum of GO–COCl (Fig. 2b), the C=O stretching vibration of the –COCl group was appeared at 1730 cm^{-1} with a low relative intensity of related peak. The low concentration of C=O functional groups to the highly amount of GO can be cause the desired peak appear in low absorption and high transmittance in the FT-IR spectra.

<Figure 2>

Fig. 3 shows XRD patterns of GO and GO-NH-IA -Cu (I). The XRD pattern of GO (Fig. 3 a) shows an intense and sharp peak centered at 11.99° which corresponds to an interplanar distance of 0.78 nm. After the functionalization, in the XRD patterns of GO-NH-IA-Cu (I), the peak at about $2\Theta= 23.7\ ^{o}$ was broad peak. Diffraction peak at $2\Theta= 42^{o}$ indicates a short range order in stacked graphene oxide layers. The reasons of this matter can be due to the covalent functionalization.

<Figure 3>

The successful covalent grafting of NH-IA-Cu (I) onto the surface of graphene oxide was further confirmed by EDX analysis. The EDX spectra of functionalized graphene oxide-Cu (I) shown in Fig. 4 that was confirmed the presence of copper, iodide and nitrogen elements in the complex.

<Figure 4>

The FE-SEM images of GO and GO-NH-IA-Cu (I) are shown in Fig. 5. As can be clearly seen in this Figure, the GO has layered structures with sheets crumpled. Fig. 5b is indicated the SEM image of GO-NH-IA-Cu (I) revealing that the layered structure can be maintained in the functionalized graphene oxide after the treatments.

<Figure 5>

3.2. Investigation of catalyst activity

This three-component reaction proceeds via in-situ formation of an alkyl azide from an alkyl halide and sodium azide. The alkyl azide then undergoes 1,3-dipolar cycloaddition reaction with terminal alkynes to give 1,4-disubstituted 1,2,3-triazoles in good to excellent yields. Here we describe a process in which GO-NH-IA-Cu (I) efficiently catalyzes azide–alkyne cycloaddition under ultrasonic irradiation (Scheme 2).

< Scheme 2>

In order to optimization of the reaction conditions, the reaction of alkyne (1 mmol), alkyl halide (1 mmol) and NaN_3 (1.1 mmol) were studied as a simple model. The reaction was carried out in the presence of different quantities of the catalyst in water-ethanol solvent (Table 1). It was found that the best result was obtained when the reaction was carried out in the presence of 0.005 g of catalyst (Table 1, entry 3).

<Table 1>

In continuation of this research, to investigate the effects of ultrasonic irradiation and to evaluate and compare conventional heating with ultrasound assisted method, we focused our efforts under different conditions. The results were listed in Table 2. As can be seen, when the catalyst was tried for the model reaction without sonication at room temperature for 2 h, was obtained any triazole as product. Also, the reaction at 80 °C temperature and without sonication for 90 min the yield of the obtained triazole was found to be only 35% (Table 2, entries 1,2). Moreover, the effect of ultrasonic irradiation of different powers was investigated. It was observed that reaction in the presence of GO-NH-IA-Cu (I) and ultrasonic irradiation power of 70 W afforded the best yield of product, with 92 % isolated yield after 7 min (Table 2, entry 5).

It was found that the ultrasound can be raised the rate of reaction and therefore reduced the energy consumption. The chemical and physical effects of ultrasound derive primarily from sonic cavitation, which includes formation, growth and collapse of the hole. The motive force for the increased efficiency of 1,4-disubstituted 1,2,3-triazoles formation by ultrasound is due to the increase of temperature related to the formation of hot spots; and due to the increase of reactant impact surface area through cavitation events.

<Table 2>

In an effort to seek improved yields and a more effective solvent, various solvents were screened in the reaction of phenylacetylene, benzyl chloride and NaN_3 in the catalytic amount of GO-NH-IA-Cu (I) as a simple reaction. With attention to the results in Table 3, in H_2O-EtOH provided excellent yields and proved to be the solvent of choice.

<Table 3>

To ascertain the scope and limitation of this reaction, some aryl halides and phenylacetylenes were reacted with sodium azide in the presence of the optimum amount of GO-NH-IA-Cu(I) under ultrasonic irradiation (Table 4). The desired 1,4-disubstituted 1,2,3-triazole derivatives were synthesized, and then characterized by spectroscopic methods. As shown in Table 4, the corresponding products were obtained in excellent yields and short reaction times under ultrasonic conditions. Moreover, the effect of various benzyl halides in this method was examined and the obtained results were provided and added to the Table 4, entries 14 and 15.

<Table 4>

A comparison of the present method with previously reported works [27, 38, 40] is reported in Table 5. As shown in this Table, the reaction of alkyne (1mmol), alkyl halide (1 mmol), NaN_3 (1.2 mmol) and GO-NH-IA-Cu(I) as catalyst the excellent yields of related products were achieved in shorter reaction times (Table 5, entries 1,3,5,7). While, in the previously reported works, the similar reaction in the presence of other catalysts afforded the corresponding products in lower yields and longer reaction times (Table 5, entries 2,4,6,8).

<Table 5>

3.3. Recycling of the catalyst

For practical applications of such heterogeneous system, the reusability is one of the important properties of the catalyst. The reusability of used catalyst was investigated using the reaction of benzyl chloride, phenylacetylene, NaN_3 and water-ethanol in the presence of GO-NH-IA-Cu (I) as a catalyst under microwave condition. The catalyst was isolated by simple filtration, washed exhaustively with water-acetone and dried. The catalyst can be reused for six runs without any treatment in its catalytic activity.

<Fig. 6>

4. Conclusion

In this study, we synthesized 1,4-disubstituted 1,2,3-triazole derivatives by reaction of a variety of alkyl halides with acetylene compounds, under the action of ultrasonic irradiation, in the presence of GO-NH-IA-Cu (I) as novel catalyst, in a 1:1 mixture of water and ethanol at room temperature. The corresponding products were obtained in excellent yields and high purity after short reaction times. The advantages of catalyst are inexpensive nature of the catalyst, reusability and stability.

Acknowledgments

The authors are grateful to the University of Kashan for supporting this work (grant no. 159148/69).

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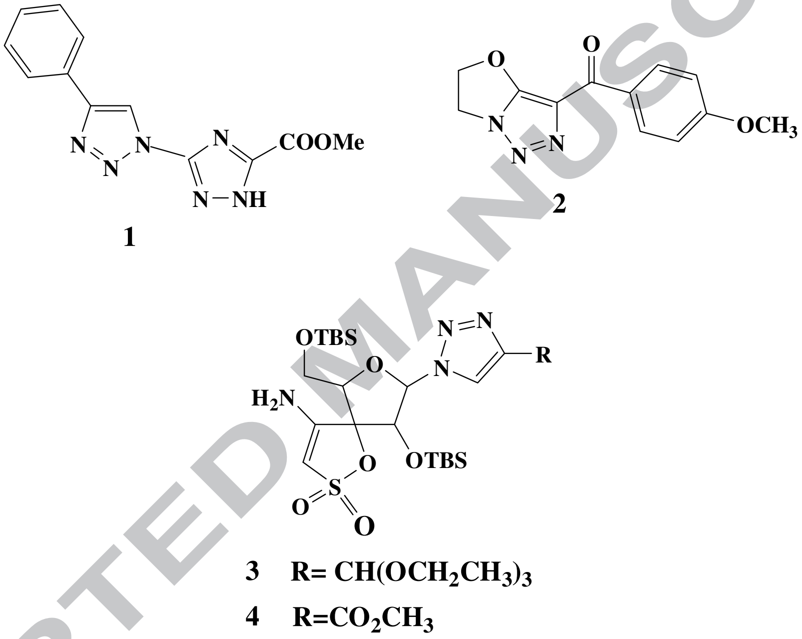


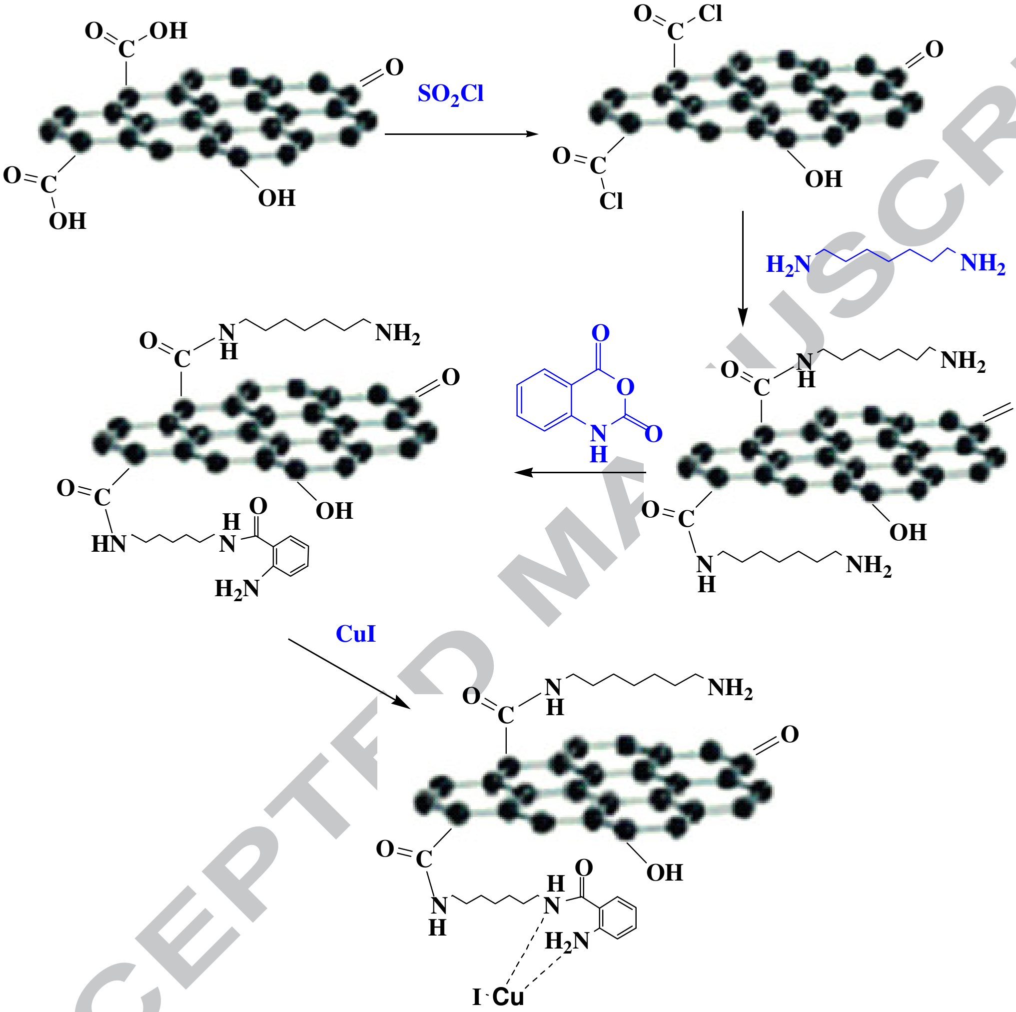
1

2

3 R= $CH(OCH_2CH_3)_3$

4 R=CO_2CH_3

Figure 1. Some examples of bioactive 1,2,3-triazoles



Scheme 1. Preparation routes of functionalized graphene oxide

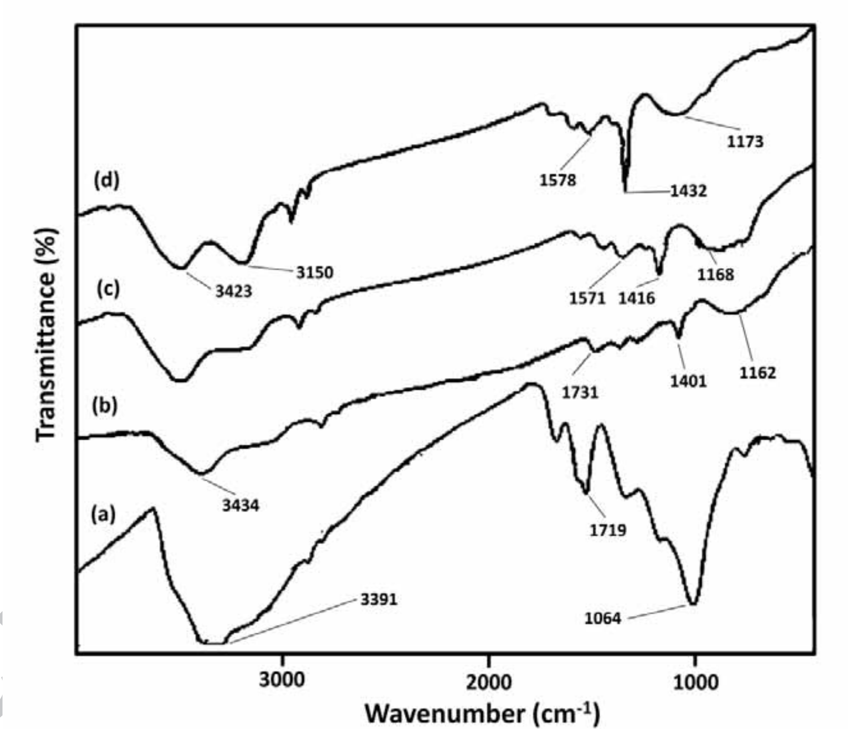


Figure 2. FT-IR spectra of a) GO, b) GO-CO-Cl c) GO-NH_2 d) GO-NH-IA

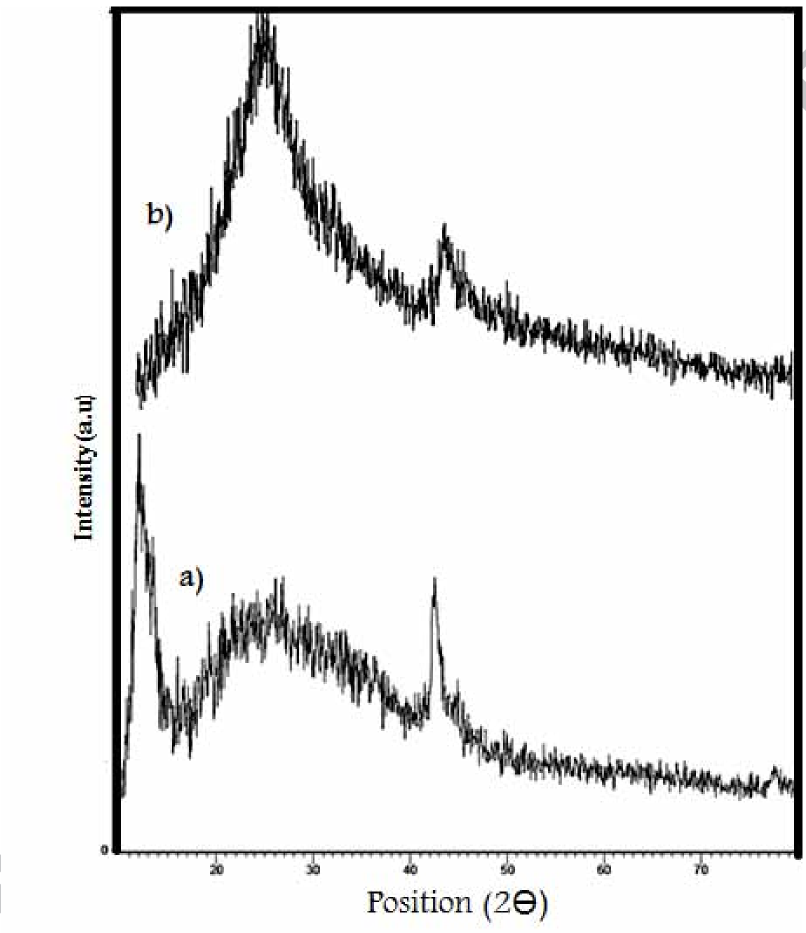


Figure3. XRD patterns of (a) GO, (b) GO-NH-IA-Cu (I)

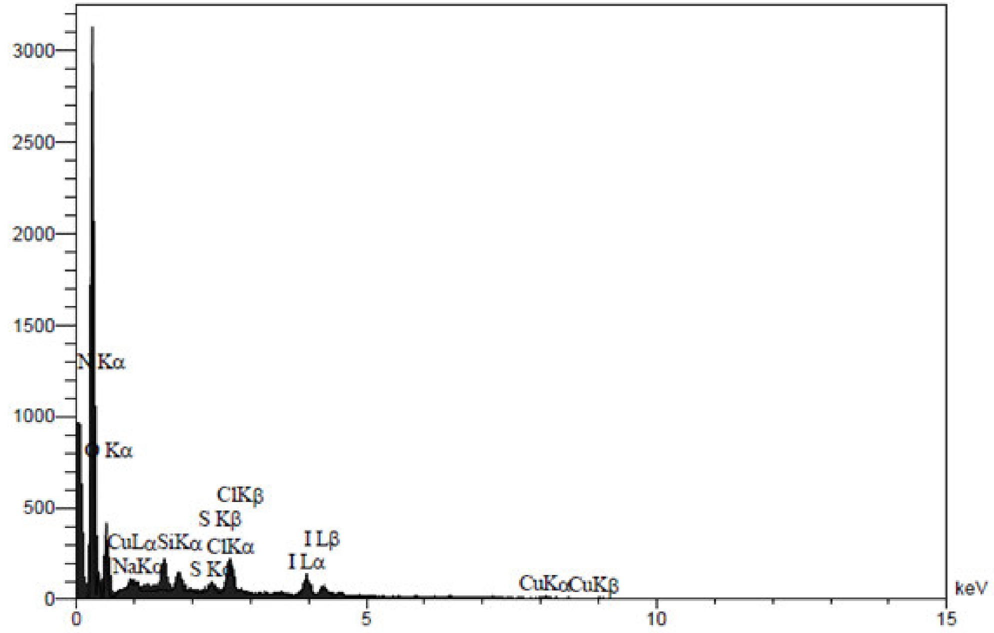


Figure 4. EDX spectra of GO-NH-IA-Cu (I)

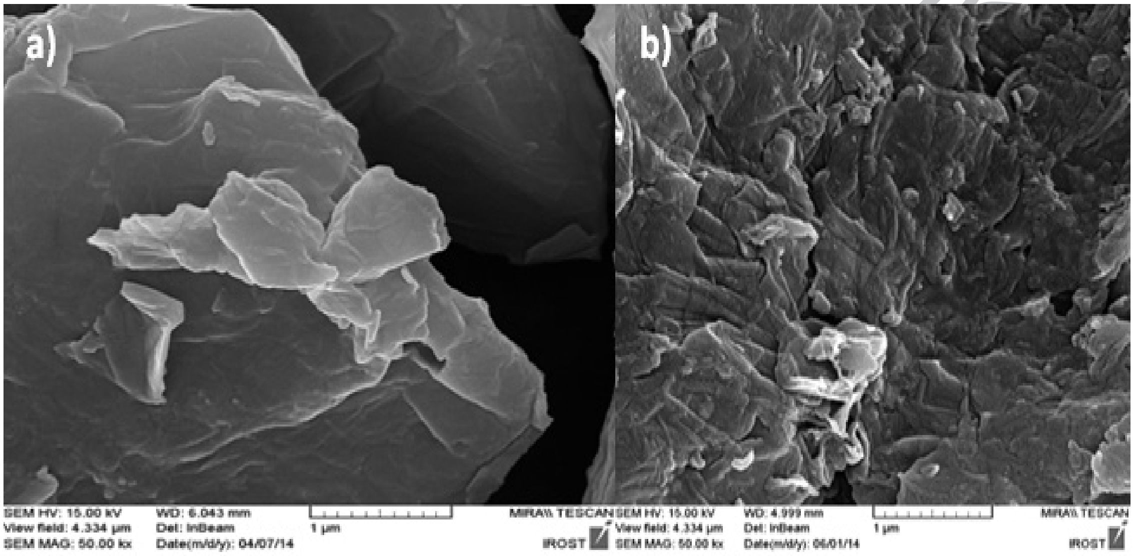
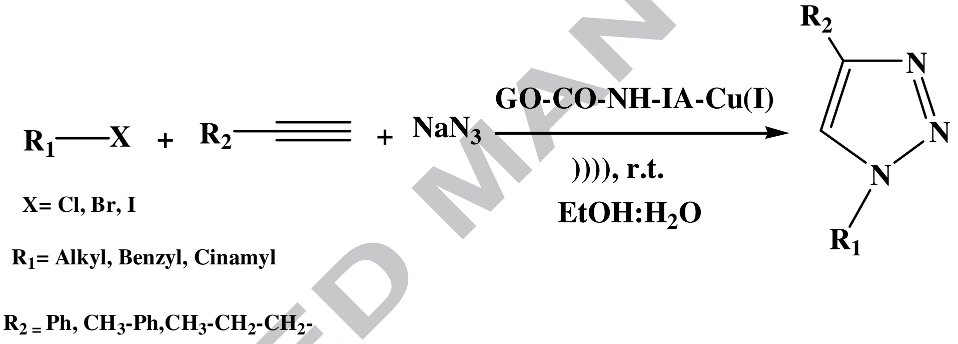


Figure 5. FE- SEM of a) GO, b) GO-NH-IA-Cu (I)



Scheme 2. Synthesis of 1,4-disubstituted 1,2,3-triazoles

Table 1. Optimization of catalyst amount for synthesis of 1,2,3-triazole[a]

Entry	Catalyst amount (g)	Time (min)	Yield (%)[b]
1	-	60	0
2	0.002	10	86
3	0.005	7	92
4	0.010	7	89
5	0.015	8	88

[a] Reaction conditions: phenylacetylene (1 mmol), benzyl chloride (1 mmol), NaN_3 (1.2 mmol) and GO-NH-IA-Cu(I) catalyst were added to the EtOH:H_2O (1:1) as solvent (6 mL) under ultrasonic irradiation (70 W) at room temperature

[b] Isolated yields

Table 2. Survey the effect of ultrasonic irradiation on the synthesis of 1,2,3-triazole

Entry	Power (W)	Time (min)	Yield (%)[a]
1	without sonication (r.t.)	120	-
2	without sonication (80°C)	90	35
3	40	12	88
4	60	10	87
5	70	7	92
6	80	8	89

Reaction conditions: 1 mmolphenylacetylene, 1 mmol benzyl chloride, 1.2 mmol NaN_3, and (0.005 gr) GO-NH-IA-Cu(I) were added to the 1:1 mixture solvent of $EtOH:H_2O$ as solvent (6 mL) under various ultrasound irradiation power at room temperature

[a] Isolated yields

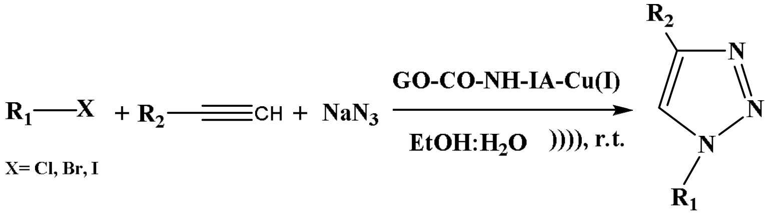
Table 3 Effect of solvent on synthesis of 1,2,3-triazole

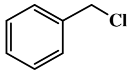
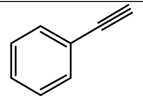
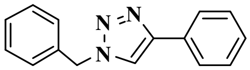
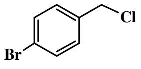
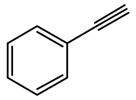
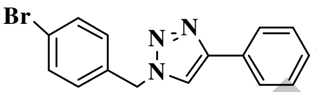
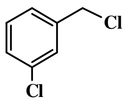
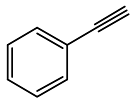
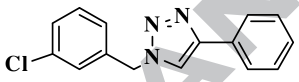
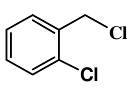
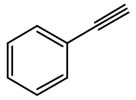
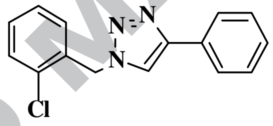
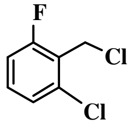
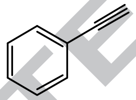
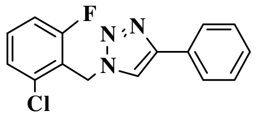
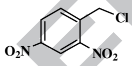
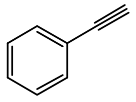
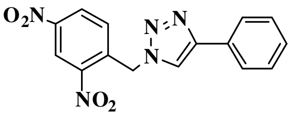
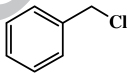
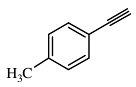
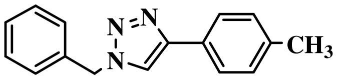
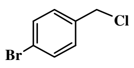
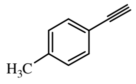
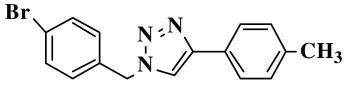
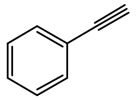
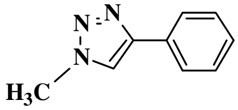
Entry	Solvent	Time (min)	Yield (%)[a]
1	EtOH	10	89
2	H_2O	10	75
3	Acetone	15	55
4	H_2O-Acetone(1:1)	8	80
5	H_2O-EtOH(1:1)	7	92

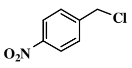
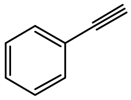
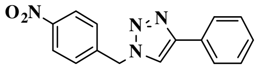
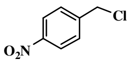
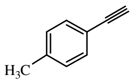
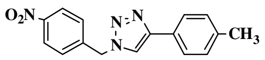
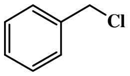
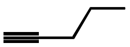
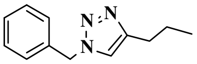
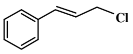
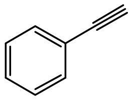
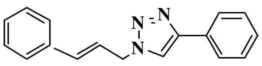
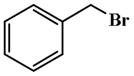
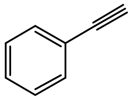
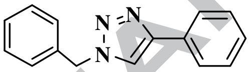
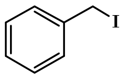
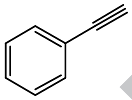
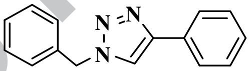
Reaction conditions: 1 mmolphenylacetylene, 1 mmol benzyl chloride, 1.2 mmol NaN_3, and (0.005 gr) GO-NH-IA-Cu (I) were added to the selected solvent (6 mL) under 70 W

[a] Isolated yields

Table 4. Preparation of 1,2,3-triazoles from the reaction of alkyl halides, phenylacetylenes, and sodium azide catalyzed by GO-NH-IA-Cu (I)

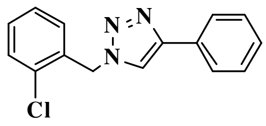
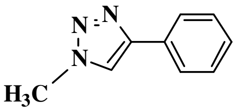
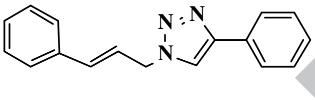
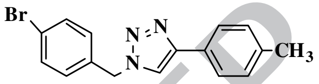


Entry	Organic halide	Alkyne	Product	Time (min)	Yield[a] (%)
1				7	92
2				8	90
3				9	88
4				10	87
5				11	84
6				12	89
7				9	93
8				10	95
9	H_3C—I			9	93

10				10	95
11				9	88
12				12	81
13				10	89
14				8	94
15				8	89

[a] Isolated yields

Table 5. Comparative study of the present method with previous works

Entry	Compound	Time (min)	Yield (%)	Ref.
1		7	92	In this work
2^a		10	91	[46]
3		9	93	In this work
4^a		10	89	[46]
5		10	89	In this work
6^b		30	80	[30]
7		10	95	In this work
8^c		12	94	[44]

a) Reaction condition: 1.05 equiv each of sodium azide and alkyne were used with 1.0 equiv of halide in 3 mL of a 1:1 water/*t*-BuOH mixture, with 50 mg of Cu turnings and 200 μL of 1 M $CuSO_4$ solution.

b) Reaction condition: halide (1.0 mmol), terminal alkyne (1.1 mmol), sodium azide (1.0 mmol), and CuI (0.001 mol) in water (5 ml)

c) Reaction condition: 1.2 mmol phenylacetylene, 1 mmol benzyl chloride, 1.5 mmol NaN_3, and 3 mol % CuI were added to the selected solvent (6 mL) under 70 W ultrasound irradiation at room temperature.

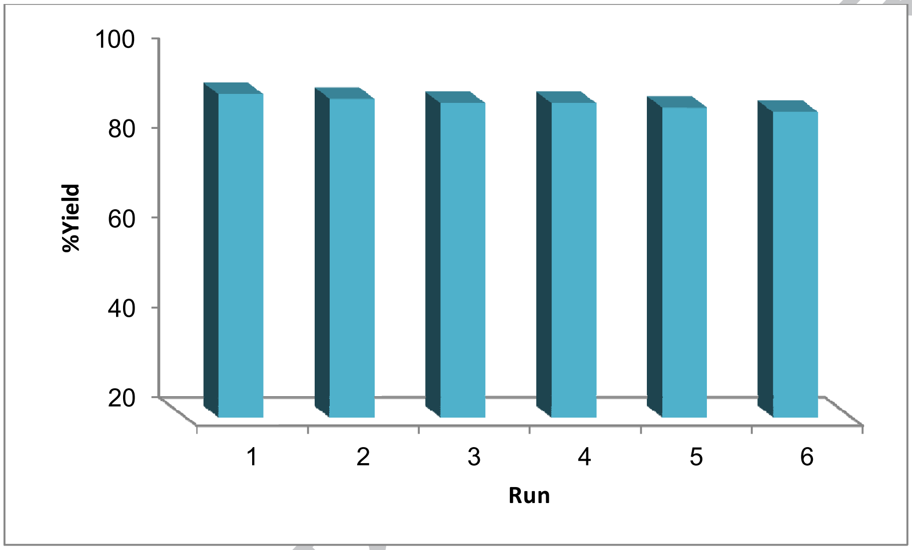


Figure 6. Reusability of catalyst for synthesis of 1,4-disubstituted 1,2,3-triazoles

Graphical abstract

Ultrasound promoted facile one pot synthesis of triazole derivatives catalyzed by functionalized graphene oxide Cu (I) complex under mild conditions

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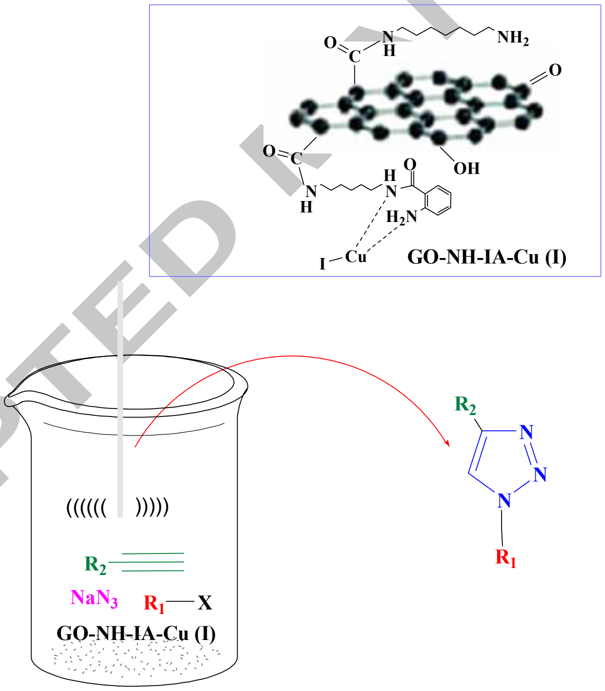
Tel: 983155912388; Fax: 983155912397; E-mail: naeimi@kashanu.ac.ir



Highlight research:

- Preparation of new functionalized graphene oxide copper (I) complex.
- Highly active and selective nanocatalyst.
- Reusability and inexpensive nature of the catalyst.
- Highly useful for economical synthesis of 1, 4-disubstituted 1, 2, 3-triazoles.
- Excellent product yields and short reaction times.