BCSJ

Graphene Oxide as a Heterogeneous Reagent Promoted Synthesis of 2-Substituted 1,3-Benzazoles in Water

Dariush Khalili[*1] **and Ali Reza Banazadeh**[2]

[1]Department of Chemistry, College of Sciences, Shiraz University, Shiraz 71454, Iran

[2]Department of Chemistry and Petrochemical Engineering, Standard Research Institute (SRI), Karaj 31745-139, Iran

E-mail: khalili@shirazu.ac.ir

Received: July 4, 2015; Accepted: August 31, 2015; Web Released: September 10, 2015

Dariush Khalili

Dariush Khalili received his B.Sc. in Chemistry from Persian Gulf University, Boushehr, Iran, in 2003. He also obtained his M.Sc. (2005) and Ph.D. (2010) in organic chemistry from Shiraz University, Iran. His Ph.D. thesis was about the synthesis of aromatic azo compounds as new reagents in Mitsunobu chemistry. He is an assistant professor in Chemistry Department of Shiraz University, Iran. His current research interests include application of carbonaceous materials and azo compounds as reagents in organic synthesis.

Abstract

An efficient chemical method for the synthesis of benzimidazoles, benzothiazoles, and benzoxazoles has been developed through the condensation of various aldehydes with *o*-phenylenediamine, *o*-aminothiophenol, and *o*-aminophenol using graphene oxide (GO) as an oxidant in water. These benzazoles are also prepared through a one-pot oxidation/condensation tandem process by reacting alcohols with 2-amino(thio)phenol/aniline in the presence of GO in poly(ethylene glycol) as a safe media. Moreover, this carbonaceous material could be readily separated using a simple filtration.

Introduction

Benzazoles including three scaffolds such as benzimidazoles, benzothiazoles, and benzoxazoles are an important class of heterocycles that can be found in a variety of natural products as well as a number of biologically active compounds.[1]

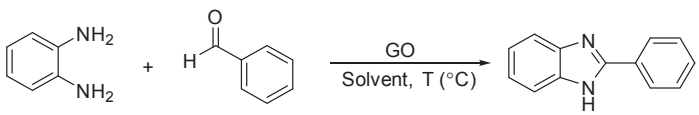
They are also considered to be suitable for nonlinear optics,[2a] organic light-emitting diodes (OLED),[2b] and liquid crystals.[2c] Therefore, development of effective methods for the synthesis of these heterocycles has drawn much attention. As it currently stands, construction of these compounds occurs via one of two general methods. One method involves transition-metal-catalyzed oxidative cyclization reactions.[3] Other methods involve the condensation reaction of 2-amino(thio)phenols/anilines with β-diketones,[4] β-ketoesters,[5] β-ketonitriles,[6a] nitriles,[6b,6c] acyl chlorides,[6d,6e] amides,[6f] esters,[6g] substituted aldehydes,[7] or carboxylic acids.[8] Although these synthetic approaches are widely used in the preparation of benzazoles, there remain many drawbacks to overcome such as the use of toxic or expensive reagents and solvents, tedious work-up procedures, poor selectivity, requirement of multistep reactions for the preparation of the starting materials and strong acidic conditions. As a result, the development of new methods for the synthesis of these heterocycles in terms of efficiency and mild reaction conditions in the presence of inexpensive reagents remains an attractive goal. Based on these facts, the use of heterogeneous systems appears to be one of the best logical solutions and carbon materials can be good candidates for this purpose. Graphene, a very recent rising star in material science, with one-atom thickness of hexagonally arrayed sp^2-bonded carbons has attracted considerable attention for its unique physical, electrical, and mechanical properties.[9] GO, a delaminated layer of graphite oxide, can be synthesized by the exhaustive oxidation of graphite using strongly acidic and oxidizing conditions followed by the subsequent exfoliation of graphite oxide.[10] Under these relatively harsh conditions, a variety of oxygen-containing functionalities such as epoxy and hydroxy groups (located on both sides of the carbon plane) and carbonyl and carboxy groups (present at the edges) are introduced into the material.[11] As a consequence, GO tends to be acidic (pH 4.5 at 0.1 mg mL^{-1}) and a strong oxidant.[11,12] Despite this potential activity, GO has been less explored as catalyst or oxidant for facilitating organic transformations. Recently GO has been used as a powerful reagent in the oxidation of sulfides and thiols,[13] alcohols,[11,14] alkenes,[15] methyl benzenes,[15] diarylmethanes,[15] 1,4-dihydropyridines[16] and as a catalyst for various transformations.[17] Inspired by this potential activity of GO, now we wish to report the first use of GO as a heterogeneous oxidant for efficient synthesis of benzazoles through the condensation of alcohols/aldehydes with 2-amino(thio)phenols/anilines. Furthermore, in these procedures, GO also can act as Brønsted acid and activates the carbonyl group of aldehydes. Compared to other oxidants used for the same transformations, GO exhibits

several advantages including facile removal from the reaction mixture, large surface area, high adsorption capability and high stability to ambient conditions.

Results and Discussion

Optimization of the reaction condition: Graphite oxide obtained directly by oxidation of graphite using the modified Hummers method.[10a,18] It has been fully characterized the results of which are given in Supporting Information. The effect of GO as an oxidant was tested in the condensation reaction between *o*-phenylenediamine (1 mmol, 108 mg) and benzaldehyde (1 mmol, 106 mg) for the synthesis of corresponding benzimidazole as a model reaction. As GO can be easily dispersed in H_2O,[19] our initial goal is to use this media for the synthesis of benzazoles. Then we studied the effect of the GO loading. The results are summarized in Table 1. The reaction between *o*-phenylenediamine **1a** and benzaldehyde in aqueous media without using GO at 60 °C was found to be very slow and the corresponding product **2a** was obtained in low yield (Entry 1). It was observed that high yield of 2-phenyl-1*H*-benzimidazole **2a** was achieved after 1 h using 100 wt % GO (108 mg of GO, with respect to *o*-phenylenediamine **1a**) at 60 °C, confirming the importance of GO in the reaction (Table 1, Entry 2). In order to find out whether the GO directly acted as oxidizing agent in the synthesis of benzazoles or functioned as a catalyst with the aid of ambient oxygen as the terminal oxidant, the aforementioned oxidation reaction was performed under an atmosphere of nitrogen. After 1 h, we got a yield of 88% of product 2-phenyl-1*H*-benzimidazole **2a**. This result proves that GO plays a crucial role in facilitating the synthesis of benzazoles and interference of ambient oxygen is negligible. In addition, to clarify the role of GO, a control experiment was performed. When the reaction was carried out under an O_2 atmosphere and 10 wt % of GO within 12 h, 12% of the benzimidazole **2a** was formed along with 84% unreacted starting material, indicating the GO was not a catalyst in the reaction. Since the difference between the yield of the product **2a** in the presence/absence of O_2 atmosphere was not remarkable, the reactions were performed in open to the air conditions. A lower yield of **2a** was obtained using 80 (86.4 mg of GO) and 60 wt % (64.8 mg of GO) GO (Entries 3 and 4). In addition, there was no egregious difference in yield and the reaction time when catalyst loading was increased to 120 wt % (Entry 5). Consequently, we decided to use 100 wt % GO for further studies. In addition to H_2O, the effect of different solvents such as acetonitrile, THF, and chloroform on the reaction outcome was investigated. The results showed that these solvents were not proper reaction media for this transformation (Table 1, Entries 6, 7, and 8). The efficiency was found also to be dependent on the reaction temperature. The results showed that 90% yield of 2-phenyl-1*H*-benzimidazole **2a** was obtained in 1 h at 60 °C (Table 1, Entry 2). However, when the reaction temperature was reduced to 40 °C, the yield of product was decreased to 75% (Table 1, Entry 9). When the temperature was raised from 60 to 90 °C a yield of 87% was attained in a reaction time of 1 h (Table 1, Entry 10). The yield of the desired product **2a** was greatly decreased when GO was replaced with other carbon promoters such as natural flake graphite, hydrazine-reduced GO[20] and activated carbon (Table 1, Entries 11, 12, and 13). In the following step, the efficiency of this protocol in the presence of other available heterogeneous oxidants such as MnO_2, CeO_2, $BaMnO_4$, and Fe_2O_3 was explored. MnO_2 and CeO_2 gave product **2a** in 61 and

Table 1. Optimization of the reaction conditions[a)]

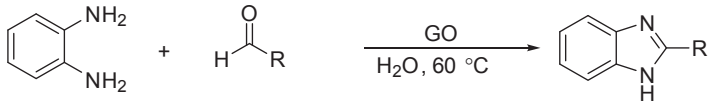


1a **2a**

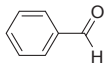
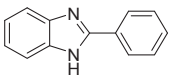
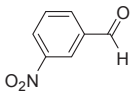
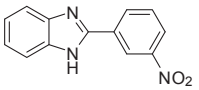
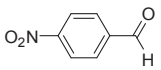
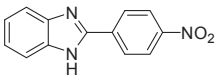
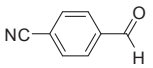
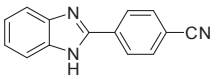
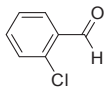
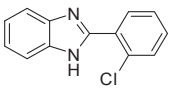
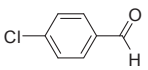
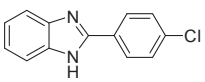
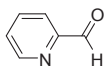
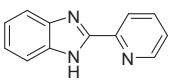
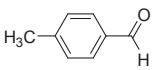
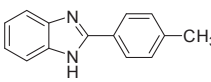
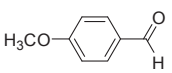
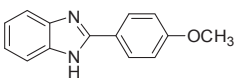
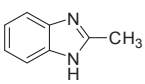
Entry	Carbon	Loading[b)]	T/°C	Solvent	Time/h	Yield/%[c)]
1	GO	—	60	H_2O	7	13[d)]
2	GO	100 wt % (108 mg)	60	H_2O	1	**90**[e)]
3	GO	80 wt % (86.4 mg)	60	H_2O	1	71
4	GO	60 wt % (64.8 mg)	60	H_2O	1	58
5	GO	120 wt % (129.6 mg)	60	H_2O	1	86
6	GO	100 wt % (108 mg)	60	CH_3CN	1	66
7	GO	100 wt % (108 mg)	60	THF	1	54
8	GO	100 wt % (108 mg)	60	$CHCl_3$	1	59
9[f)]	GO	100 wt % (108 mg)	40	H_2O	1	75
10	GO	100 wt % (108 mg)	90	H_2O	1	87
11	Graphite	100 wt % (108 mg)	60	H_2O	6	16
12	hydrazine-reduced GO	100 wt % (108 mg)	60	H_2O	6	22
13	activated carbon	100 wt % (108 mg)	60	H_2O	6	17
14	MnO_2	100 wt % (108 mg)	60	H_2O	6	61
15	CeO_2	100 wt % (108 mg)	60	H_2O	6	55
16	$BaMnO_4$	100 wt % (108 mg)	60	H_2O	6	46
17	Fe_2O_3	100 wt % (108 mg)	60	H_2O	6	73

a) Reaction conditions: *o*-phenylenediamine **1a** (1 mmol, 108 mg), benzaldehyde (1 mmol, 106 mg), carbon (type indicated), solvent (3 mL). b) With respect to *o*-phenylenediamine **1a**. c) Isolated yields. d) Blank experiment in water without GO. e) Bold value signifies best reaction conditions. f) After 7 h, 79% of **2a** was produced.

Table 2. Synthesis of benzimidazoles using GO (GO) in neat water[a)]



1a **2a-j**

Entry	Aldehyde	Product		Time	Yield[b)]/%
1			**2a**	1 h	90
2			**2b**	1 h	92
3			**2c**	45 min	95
4			**2d**	45 min	93
5			**2e**	3 h	83
6			**2f**	2 h	88
7			**2g**	45 min	91
8			**2h**	4 h	85
9			**2i**	4 h	81
10[c)]			**2j**	5.5 h	78

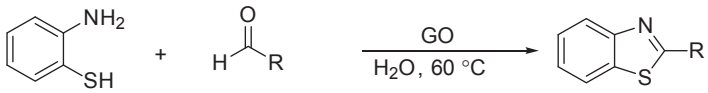
a) Reactions were carried out with *o*-phenylenediamine **1a** (1 mmol), aldehydes (1 mmol), GO (100 wt %) in water (3 mL), 60 °C. b) Isolated yields. c) Reaction was performed in a sealed tube.

55% yields, respectively (Table 1, Entries 14 and 15). In these cases, 1,2-disubstituted benzimidazole was formed as by-product. When the $BaMnO_4$ was used, the desired product **2a** was formed in 46% yield (Table 1, Entry 16). As shown in Table 1, Fe_2O_3 afforded better yield (73%, Entry 17). Therefore, GO proved to be the best choice among the screened heterogeneous oxidants under the reaction conditions.

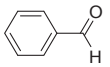
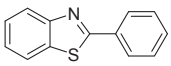
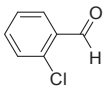
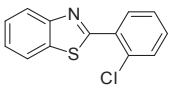
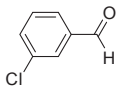
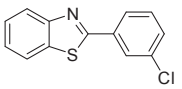
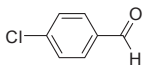
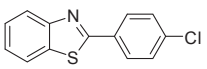
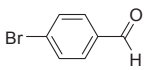
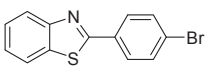
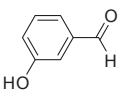
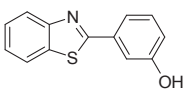
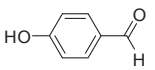
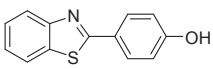
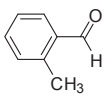
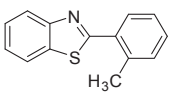
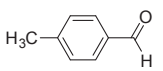
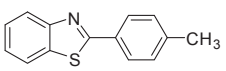
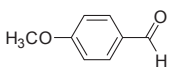
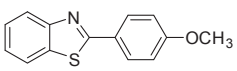
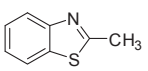
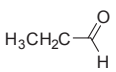
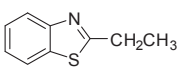
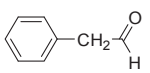
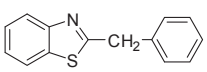
With the optimized conditions, the scope of the process was subsequently investigated (Table 2). As shown in Table 2, benzaldehydes with both electron-donating and -withdrawing groups participated in the condensation reaction and gave the desired benzimidazoles in high to excellent yields. The reaction of 3 and 4-nitobenzaldehyde with *o*-phenylenediamine afforded products **2b** and **2c** in 92% and 95% yields, respectively (Entries 2 and 3).

Likewise, the reactions of 4-cyanobenzaldehyde occurred and afforded the corresponding benzimidazole **2d** under identical conditions (Table 2, Entry 4). Halogen-containing aldehydes, such as 2-chloro- and 4-chlorobenzaldehyde can be employed as substrates in this methodology to provide the expected products **2e** and **2f** in 83%–88% yields, respectively (Table 2, Entries 5 and 6). 2-Pyridinecarboxaldehyde as an electron-deficient substrate can react with *o*-phenylenediamine **1a** smoothly with the formation of the corresponding benzimidazole **2g** in 91% yield (Entry 7). The aldehydes with electron-donating groups also participated in the reaction. For example 4-methyl- and 4-methoxybenzaldehydes were suitable substrates for the reaction, and the respective products **2h** and **2i** were obtained in satisfactory yields (Table 2, Entries 8 and 9). Furthermore, this system could also be applied for aliphatic aldehydes such as acetaldehyde in moderate yields (Table 2, Entry 10). These results showed that aldehydes bearing electron-withdrawing groups resulted in better results than those bearing electron-donating groups. This variation in product yields with nature and position of substituents may be due to inductive and steric effects.

Table 3. Reaction of *o*-aminothiophenol with various aldehydes in presence of GO for synthesis of 2-substituted benzothiazoles[a)]



3a **4a-n**

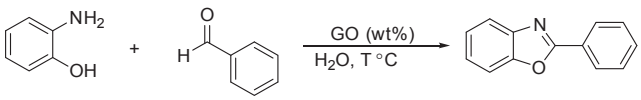
Entry	Aldehyde	Product		Time/h	Yield/%[b),c)]
1			**4a**	5	87
2			**4b**	4	79
3			**4c**	4	87
4			**4d**	4	88
5			**4e**	4	84
6			**4f**	6	77
7			**4g**	6.5	72
8			**4h**	8	66
9			**4i**	7	68
10			**4j**	8	64
11[d)]			**4k**	8	61
12[d)]			**4l**	8	56
13			**4m**	7	69

a) Reactions were carried out with *o*-aminothiophenol **3a** (1 mmol, 125 mg), aldehydes (1 mmol), GO (100 wt %, 125 mg) in water (3 mL), 60 °C. b) Isolated yields. c) Products were characterized using NMR and compared with the reported data. d) Reaction was performed in a sealed tube.

After establishing the activity of the methodology for benzimidazoles, we attempted to further apply this protocol to the preparation of benzothiazoles. The procedure that was used for the synthesis of benzimidazoles expanded to the synthesis of benzothiazoles from *o*-aminothiophenol **3a** and various aldehydes. To our satisfaction, it was found that the reaction between *o*-aminothiophenol **3a** (1 mmol, 125 mg) and benzaldehyde (1 mmol, 106 mg) in the presence of 100 wt % of GO (125 mg, with respect to *o*-aminothiophenol **1a**) in H_2O as solvent at 60 °C went smoothly and gave the desired 2-phenylbenzothiazole **4a** in 87% yield within 5 h. No reaction occurred without the GO. With the optimized oxidation/condensation conditions in hand, the substrate scope with both aromatic and aliphatic aldehydes was investigated. These results are presented in Table 3.

79–88% of halogen-substituted benzothiazoles **4b**–**4e** was produced from their parent benzaldehydes under the same reaction conditions (Entries 2–5). Even sterically demanding *ortho*-substituted aldehyde (Table 3, Entry 2) resulted in good yield. Aldehydes with an electron-rich ring such hydroxy-, methyl-, and methoxybenzaldehydes (Entries 6–10) also resulted in moderate yields demonstrating the generality of the reaction.

Table 4. The screening of GO loading and temperature[a)]



5a 6a

Entry	GO loading /wt %[b)]	Temperature /°C	Time /h	Yield /%[c)]
1	100 (109 mg)	60	12	46
2	110 (120 mg)	60	12	54
3	120 (130.8 mg)	60	10	59
4	120 (130.8 mg)	80	7	71
5	120 (130.8 mg)	90	7	83

a) Reactions were performed using *o*-aminophenol **5a** (1 mmol, 109 mg), benzaldehyde (1 mmol, 106 mg), GO (amount indicated), H_2O (3 mL). b) With respect to *o*-aminophenol **5a**. c) Isolated yields.

Aliphatic substrates were also suitable for the reaction. However, in the case of these aldehydes, low yield of products was observed. For example, acetaldehyde, propanal and 2-phenylacetaldehyde reacted with *o*-aminothiophenol **3a** in the presence of GO (100 wt %) in H_2O to give the corresponding products **4k–4m** in 61%, 56%, and 69% yields respectively (Table 3, Entries 11–13).

Having now developed an efficient procedure for synthesis of benzimidazoles and benzothiazoles and also to extend the scope of this methodology, we also examined condensation of aldehydes with *o*-aminophenol to give their corresponding benzoxazole derivatives under the same reaction conditions. To effect this transformation, the reaction between *o*-aminophenol (**5a**) and substituted aldehydes in the presence of GO (100 wt %) in H_2O as solvent at 60 °C was studied.

However, in the case of benzaldehyde as a model substrate, very poor conversion to benzoxazole **5a** was observed. So, stronger reaction conditions were assayed: While 100 wt % GO afforded 46% of the target product in 12 h (Table 4, Entry 1), better yields were obtained by increasing the loading of GO to 120 wt % (10 h, 59%) (Table 4, Entry 3). Further increasing the loading of GO did not enhance the reaction yield. It was also noted that variations in the reaction temperature had a significant effect on the isolated yield of the benzoxazole product. Table 4 implied that the yield was improved when the temperature increased from 60 to 90 °C (Table 4, Entries 3–5). Thus, the optimum reaction conditions were obtained as follows: *o*-aminophenol (**5a**) (1 mmol), aldehydes (1 mmol), 120 wt % GO as an oxidant, H_2O as solvent, and the reaction temperature at 90 °C for appropriate time. With optimal reaction conditions in hand, we then turned our attention to investigate the scope of substrates, and the results are shown in Table 5.

A series of substituted aldehydes were employed to prove the general applicability of our present procedure. In general, aldehydes with electron-withdrawing groups were more reactive than aldehydes with electron-donating groups and required shorter reaction time (Table 5, Entries 2–6 compared to Entries 7–9).

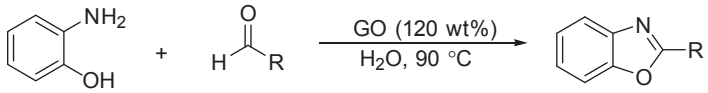
Nitrobenzaldehydes generated the corresponding benzoxazoles **6b** and **6c** with high yields (85–87%, Entries 2 and 3). When halogen-containing benzaldehydes were examined as substrates, the desired benzoxazoles **6d–6f** were obtained in good yields (Table 5, Entries 4–6). Notably, electron-rich aldehydes, such as 2-, 3-, and 4-hydroxybenzaldehydes, can be employed as substrates in this methodology to provide the expected products **6g–6i** in 62%, 66%, and 63% yields, respectively (Table 5, Entries 7–9). In fact in this series, slow condensation-oxidation tandem reaction of electron-rich benzaldehydes can be attributed to a low electrophilicity of such substrates.[21] Reactions of aliphatic alcohols such as acetaldehyde (Table 5, Entry 10), propanal (Table 5, Entry 11), and 2-phenylacetaldehyde (Table 5, Entry 12) with *o*-aminophenol (**5a**) in the presence of 120 wt % of GO in water at 90 °C afforded corresponding benzoxazoles **6j–6l** in low yield, and these yields were not improved by changing the conditions. In general, the observed trend in yields is in agreement with that of condensation-oxidation tandem reaction of aldehydes with 2-amino(thio)phenols/anilines in previous studies.

Sequential oxidation and condensation of alcohols with aromatic diamines (via in situ generation of aldehydes) is an attractive approach to imidazoles in view of the fact that alcohols are commercially available and serve as starting materials for a multitude of other reactions. A literature survey revealed only a few reports on the direct conversion of alcohols into benzazoles.[22] In view of the above perceptions, various benzyl alcohols are chosen as starting substrates in a one-pot oxidation/condensation tandem process for the synthesis of benzazoles. Our studies were focused on the optimization of reaction conditions based on benzyl alcohol (1.2 mmol) and *o*-phenylenediamine **1a** (1 mmol) as model substrates (Table 6).

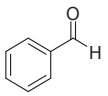
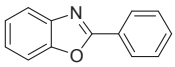
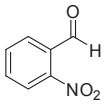
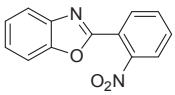
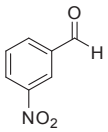
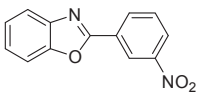
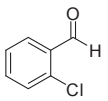
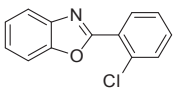
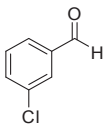
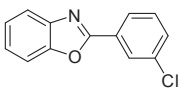
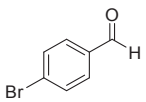
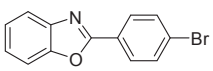
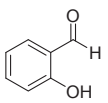
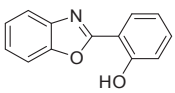
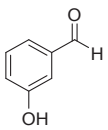
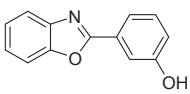
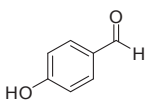
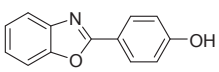
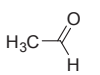
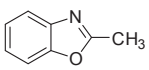
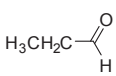
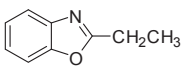
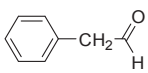
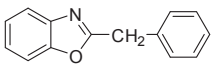
Experimentally, for the initial step of oxidation, benzyl alcohol (1.2 mmol) and different amounts of GO were heated (to *T* °C) in a solvent until almost all benzyl alcohol was oxidized (the aldehyde formation was monitored by TLC/gas chromatography, ^{1}H NMR and ^{13}C NMR). Then this process was followed by addition of *o*-phenylenediamine **1a** (1 mmol) and allow it to stir (at *T* °C) for the appropriate time. The screening results of the model reaction are summarized in Table 6.

To investigate possible solvent effects in our process, several organic solvents were screened. When the oxidation/condensation tandem reaction between benzyl alcohol and *o*-phenylenediamine **1a** (1 mmol, 108 mg) was performed in water in the presence of 200 wt % of GO (216 mg, with respect to *o*-phenylenediamine **1a**), the reaction did not occur and the starting materials were recovered after 10 h (Table 6, Entry 1). The reaction of benzyl alcohol with *o*-phenylenediamine in the presence of 300 wt % of GO produced trace **2a** after 10 h (Table 6, Entry 2). When acetonitrile was employed as a solvent (200 wt % of GO), 29% of the product 2-phenyl-1*H*-benzimidazole **2a** was observed (Table 6, Entry 3). Test reaction with 300 wt % of GO in acetonitrile at 60 °C gave product **2a** in 36% (Table 6, Entry 4). In $CHCl_3$, CH_2Cl_2, and THF the efficiency of the oxidative condensation decreased and 25%, 19%, and 31% of **2a** were obtained respectively (Table 6, Entries 5–7). When the reaction proceeded in toluene[14b] using 200 wt % of GO at 60 and 110 °C, the corresponding product **2a** was obtained in 39% and 46% yields (Table 6, Entries 8 and 9). Improved yield of **2a** (55%) was achieved in refluxing toluene with 300 wt % of GO (Table 6, Entry 10). Since our main goal

Table 5. Substrate generality for the synthesis of benzoxazoles promoted by GO (GO)[a)]



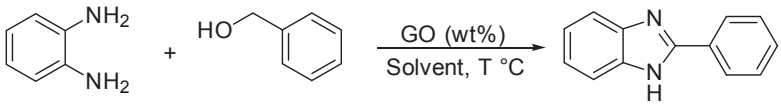
5a **6a-l**

Entry	Aldehyde	Product		Time/h	Yield/%[b)]
1			**6a**	7	83
2			**6b**	6	85
3			**6c**	6	87
4			**6d**	6	80
5			**6e**	6	75
6			**6f**	7	71
7			**6g**	10	62
8			**6h**	9	66
9			**6i**	10	63
10[c)]			**6j**	12	56
11[c)]			**6k**	12	39
12			**6l**	12	44

a) Reagents and conditions: *o*-aminophenol **5a** (1 mmol, 109 mg), benzaldehydes (1 mmol), GO (120 wt %, 130.8 mg), water (3 mL), 90 °C. b) Yields of products after isolation by column chromatography. c) Reaction was performed in a sealed tube.

was to use a safe media for our reactions, we decided to use poly(ethylene glycol) (PEG) instead of these solvents. PEG is a valid candidate towards the goal of green chemistry.[23] When the reaction was carried out using 200 wt % of GO in PEG-200 at room temperature, 36% of 2-phenyl-1*H*-benzimidazole **2a** was obtained after 10 h (Table 6, Entry 11). When the temperature was raised to 60 °C (with 200 wt % of GO), the yield of **2a** was 50% (Table 6, Entry 12). Oxidation/condensation tandem reaction between benzyl alcohol and *o*-phenylenediamine **1a** gave 63% yield of **2a** with 200 wt % of GO when the

Table 6. Optimization of the one-pot oxidation/condensation tandem reaction for synthesis of benzimidazole: effect of GO loading and solvent[a)]



1a **2a**

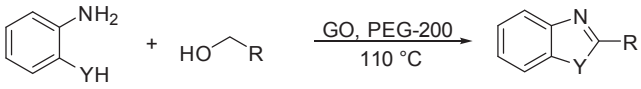
Entry	GO loading (wt %)[b)]	Solvent (condition)	Yield/%[c)]
1	200 (216 mg)	H_2O, 60 °C	—
2	300 (324 mg)	H_2O, 60 °C	Trace
3	200 (216 mg)	CH_3CN, 60 °C	29
4	300 (324 mg)	CH_3CN, 60 °C	36
5	300 (324 mg)	CH_3Cl, 60 °C	25
6[d)]	300 (324 mg)	CH_2Cl_2, 60 °C	19
7	300 (324 mg)	THF, 60 °C	31
8	200 (216 mg)	Toluene, 60 °C	39
9	200 (216 mg)	Toluene, reflux	46
10	300 (324 mg)	Toluene, reflux	55
11	200 (216 mg)	PEG-200, room temperature	36
12	200 (216 mg)	PEG-200, 60 °C	50
13	200 (216 mg)	PEG-200, 110 °C	63
14[e)]	300 (324 mg)	PEG-200, 110 °C	**73**

a) Reactions were performed using benzyl alcohol (1.2 mmol), *o*-phenylenediamine **1a** (1 mmol, 108 mg), GO (amount indicated), solvent (3 mL). b) With respect to *o*-phenylenediamine **1a**. c) Isolated yields. d) Reaction was performed in a sealed tube. e) Bold value signifies best reaction conditions.

temperature was raised to 110 °C (Entry 13). On increasing the amount of GO to 300 wt %, yield of benzimidazole product **2a** increased to 73% (Table 6, Entry 14). Further increase in GO loading and temperature did not change the product yield. In addition, without GO, no formation of the desired product was observed. Generally, a mixture of benzyl alcohol (1.2 mmol) and GO was stirred vigorously at 110 °C in PEG-200 until nearly all benzyl alcohol was oxidized. This was followed by the addition of *o*-phenylenediamine **1a** (1 mmol) to the resulting mixture and allowing it to stir at 110 °C for the appropriate time, giving 2-phenyl-1*H*-benzimidazole **2a** in 73% yield over two steps (overall reaction time 10 h). Investigation on the effect of GO loading and reaction temperature implied that 300 wt % of GO at 110 °C is most proper for optimal results. Because the GO was serving in multiple roles in this reaction, higher loadings were employed to increase the yield of product.[17g] As a result, PEG-200 was selected as the media of choice for the synthesis of benzimidazoles from benzyl alcohols and *o*-phenylenediamine **1a** in the presence of 300 wt % of GO at 110 °C. To explore the scope and efficacy of this process, a set of alcohols with *o*-phenylenediamine **1a** were used for the synthesis of benzimidazoles. The results were shown in Table 7.

Additionally, to evaluate the strengths and scope of this system, we further extended our study to the sequential oxidation and condensation of alcohols with *o*-aminothiophenol **3a** and *o*-aminophenol **5a** to produce the benzothiazoles and benzoxazoles under the same conditions utilized for the synthesis of benzimidazoles from alcohols. The obtained results are summarized in Table 7. In general, benzylic alcohols with either electron-donating or electron-withdrawing groups were well tolerated in this reaction system. As Table 7 shows, electron-donating groups on benzyl alcohol accelerate the reaction rate in comparison to electron-withdrawing groups which decrease the rate. When nitrobenzyl alcohol was subjected to the reaction conditions, benzazoles **2c**, **4b**, and **6b** were obtained in 55%, 54%, and 50% yields respectively (Table 7, Entries 2, 9, and 18). Halo-substituted benzyl alcohols reacted with **1a**, **3a**, and **5a** in the presence of GO and the corresponding benzazoles **2e**, **2f**, **4c**–**4e**, and **6d**–**6f** were obtained with moderate yields (Entries 3, 4, 10, 11, 12, 19, 20, and 21). The *ortho*-substituted benzyl alcohols such as *o*-chlorobenzyl alcohol (Entries 3, 10, and 19) decrease the rate of the reaction and gave poor yield compared to the *p*-chlorobenzyl alcohol. This may be due to the steric effect of halogen group at the ortho position. When sequential oxidation and condensation was carried out with benzyl alcohols having electron-releasing substituent such as $-CH_3$ and $-OCH_3$ (Table 7, Entries 5, 6, 13, 14, and 23), benzazole products were obtained in good yields. In the case of non benzylic alcohols, such as ethanol and 2-phenylethanol, the reactivities were very low and poor yields of the desired products were obtained (Table 7, Entries 7, 15, 16, 24, and 25). To gain further insights into this synthetic route and find supporting evidence for the oxidation of alcohols and formation of aldehydes, reaction of benzyl alcohol in oxidation/condensation tandem process for the synthesis of corresponding benzimidazole was selected as a model reaction. Our investigation started by treating benzyl alcohol (1.2 equiv) with GO (300 wt %) in PEG-200 at 110 °C. This reaction was stopped at about 8 h after the reaction began and the residual carbon was separated from the reaction by simple filtration. In addition to GC and TLC analysis, formation of benzaldehyde was also supported by ^1H and ^{13}C NMR spectra. The ^1H and ^{13}C NMR spectra of the isolated benzaldehyde in $CDCl_3$

Table 7. Sequential oxidation and condensation for synthesis of benzazoles[a)]



Y = NH (**1a**), S (**3a**), O (**5a**)

Entry	Y	R	Product	Time/h	Yield/%[b)]
1	NH	Ph-	**2a**	10	75
2	NH	4-NO_2-C_6H_4-	**2c**	10	55
3	NH	2-Cl-C_6H_4-	**2e**	10	60
4	NH	4-Cl-C_6H_4-	**2f**	10	70
5	NH	4-Me-C_6H_4-	**2h**	10	76
6	NH	4-OMe-C_6H_4-	**2i**	10	85
7[c)]	NH	CH_3-	**2j**	10	36
8	S	Ph-	**4a**	12	71
9	S	4-NO_2-C_6H_4-	**4b**	12	54
10	S	2-Cl-C_6H_4-	**4c**	12	51
11	S	3-Cl-C_6H_4-	**4d**	12	68
12	S	4-Cl-C_6H_4-	**4e**	12	71
13	S	4-OH-C_6H_4-	**4h**	12	78
14	S	4-Me-C_6H_4-	**4j**	12	72
15[c)]	S	CH_3-	**4l**	12	44
16	S	$PhCH_2$-	**4n**	12	52
17	O	Ph-	**6a**	18	80
18	O	2-NO_2-C_6H_4-	**6b**	18	50
19	O	2-Cl-C_6H_4-	**6d**	18	53
20	O	3-Cl-C_6H_4-	**6e**	18	62
21	O	4-Br-C_6H_4-	**6f**	18	67
22	O	3-OH-C_6H_4-	**6h**	18	71
23	O	4-OH-C_6H_4-	**6i**	18	82
24[c)]	O	CH_3-	**6j**	18	44
25	O	$PhCH_2$-	**6l**	18	52

a) Condition: 2-amino(thio)phenol/aniline (1 mmol), alcohols (1.2 mmol), GO (300 wt %), PEG-200 (2 mL), 110 °C. b) Isolated yields. c) Reaction was performed in a sealed tube.

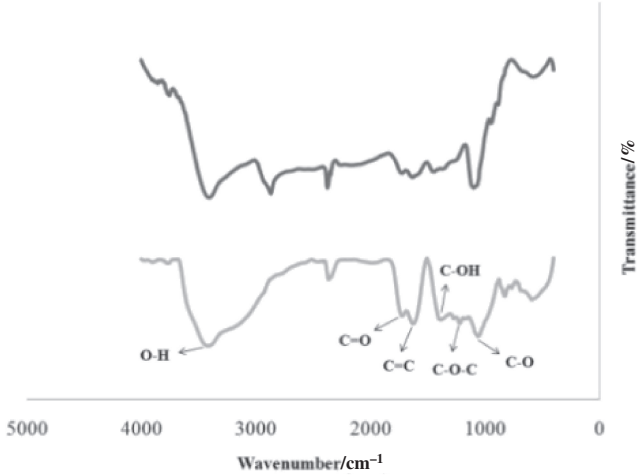


Figure 1. IR spectrum of separated GO (up) after oxidation of benzyl alcohol and fresh GO (down).

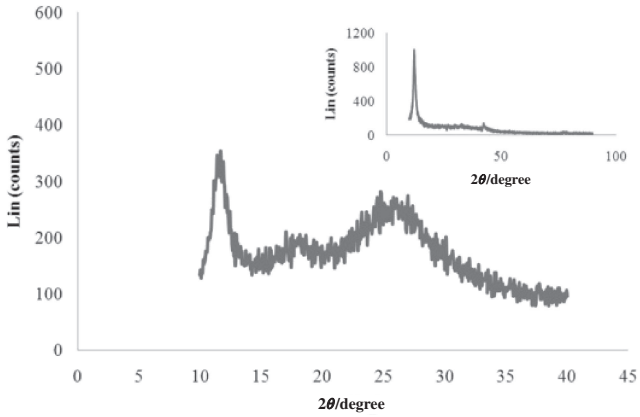


Figure 2. XRD patterns of separated GO after oxidation of benzyl alcohol and GO (inset).

showed the presence of the C*HO* proton and the *C*HO carbon at 9.84 and 192.3 ppm, respectively, which are indicative of the formation of benzaldehyde as a product. The resulting carbon material was characterized by infrared analysis (FT-IR) and X-ray diffraction (XRD). Generally, in IR analysis, peaks of the main functional groups of separated GO were observed but became broader and weaker compared to GO starting material. FT-IR of the separated GO exhibited characteristic absorption bands of O–H at 3405 cm^{-1}. The peaks at around 1734, 1637, 1374, and 1098 cm^{-1} correspond to carboxyl group, C–C stretching and absorbed hydroxy groups, C–OH, and C–O stretching models of the GO, respectively (Figure 1).

The separated GO was also charcterized by X-ray diffraction method. As can be seen (Figure 2), the peak intensity at 11.78° decreased and a new broad peak with the maximum at $2\theta =$ 26.2° appeared, corresponding to the *d*-spacing of 0.33 nm along the (002) orientation. The observation of characteristic d_{002} reflection of graphite at 26.2 gave evidence that partial reduction was achieved.[19c]

To determine the fate of the GO used in the aforementioned reactions, a control reaction was carried out using *o*-phenylenediamine **1a** (1 mmol) and benzaldehyde (1 mmol) in aqueous media in the presence of GO (100 wt %) at 60 °C. At the end of the reaction, the residual carbon was separated from the reaction by filtration and the resulting material was characterized. Compared to the GO starting material, the FT-IR spectrum (KBr) of the recovered GO exhibited a attenuated signal at $\nu = 3150\ cm^{-1}$ (O–H stretch), as well as the disappearance of diagnostic signals at 1366 cm^{-1} (C–OH) and 1064 cm^{-1} (attributed to C–O) (Figure 3).

The FTIR spectrum also revealed new signals at 1538 cm^{-1}, which was attributed to the presence of aromatic or olefinic species (Figure 3). Additionally, elemental analysis of the isolated carbon material showed a higher carbon content (68.22%) than the GO starting material (49.98%). These results suggested that the GO underwent partial reduction during the synthesis of benzazoles. Besides FT-IR results, partial reduction of GO sheets was also confirmed by X-ray diffraction (XRD). Figure 4 shows the XRD pattern of the recovered GO after the reaction between *o*-phenylenediamine **1a** and benzaldehyde in aqueous media at 60 °C.

As can be seen, the main peak of GO at 11.78° decreased and a new peak at $2\theta = 25.6°$ appeared. This can be explained by the partial removal of oxygen functional groups, causing a

decrease in *d*-spacing.[19c] These changes indicate that the heterogeneous nature of the oxidized graphite was comprised of both sp^2 and sp^3 domains from graphite and GO, respectively.

We also checked the reusability of the GO for the condensation-oxidation reaction of *o*-phenylenediamine **1a** and benzaldehyde in aqueous media at 60 °C to form 2-phenyl-1*H*-benzimidazole **2a**. After completion of the reaction, GO was removed by simple filtration, washed with diethyl ether (20 mL) and warm ethanol several times and then dried under vacuum. A new reaction was then conducted with fresh reactants under similar conditions. The decrease in the yield of the product **2a** from 90% to 51 and 26% for the second and third runs confirms again that GO has lost some of its oxidative property. In addition, to confirm that the observed reactivity of GO in the synthesis of benzazoles was not mediated by the residual Mn, which may have remained from $KMnO_4$ used in the preparation of GO, inductively coupled plasma atomic emission spectroscopy (ICP-AES) was performed on an aqueous dispersion of GO. In particular, the manganese content was found to be <50 ppb (approximately equivalent to other native metal contaminants found in the material).[11,15,17g]

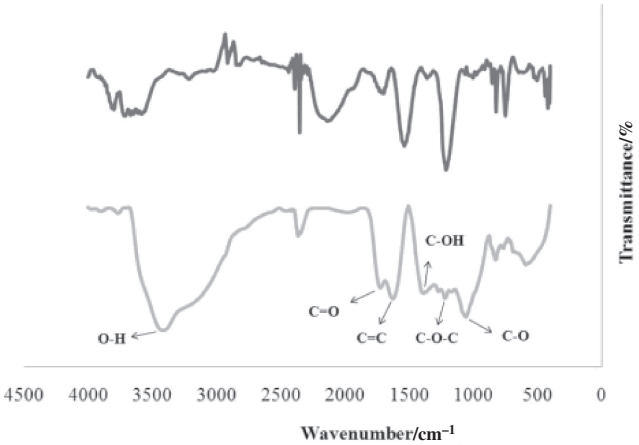


Figure 3. IR spectrum of GO (light gray) and GO after 1 run (dark gray).

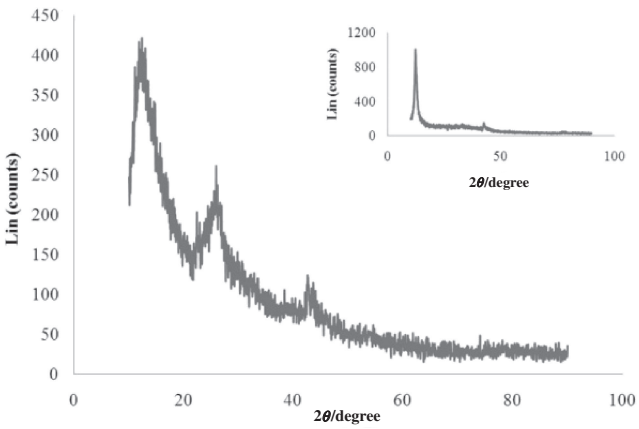


Figure 4. XRD patterns of GO and GO after 1 run of reaction (inset).

According to the known literature and results obtained in our experiments, a mechanism is proposed for the synthesis of benzazoles as shown in Figure 5. First, the GO as a Brønsted acid[17] and water as a ambiphilic dual activation catalysis[24] approaches and activates the carbonyl group of the aldehyde. Subsequently, reaction of activated aldehyde with aryl amino function produces imine intermediate **I** and this is followed by an intramolecular ring closure to produce the N,Y-acetal **II**. Finally acetal **II** undergoes aromatization and dehydrogenation (oxidation) by GO to give benzazole **III** as shown in Figure 5. In fact, in the final step of this mechanism, GO acts as a stoichiometric oxidant. In the oxidation/condensation tandem reaction between alcohols and 2-amino(thio)phenol/aniline, first, alcohol is oxidized to its corresponding aldehyde in the presence of GO. In the next step, GO activates the in situ produced aldehyde and then aldehyde is condensed with 2-amino(thio)phenol/aniline to generate 2-substituted benzazoles. In order to understand the role of GO for the imine formation, a control experiment was performed with an equimolar ratio of benzaldehyde (1.0 equiv) and *o*-phenylenediamine **1a** (1.0 equiv) in the absence of the catalyst under standard reaction conditions. This transformation yielded no product **2a** other than 14% imine after 1 h. This result is in accordance with those reported for the imine formation in the Strecker reaction.[25] This observation also supports the key role of GO to activate aldehyde. To investigate the role of the active

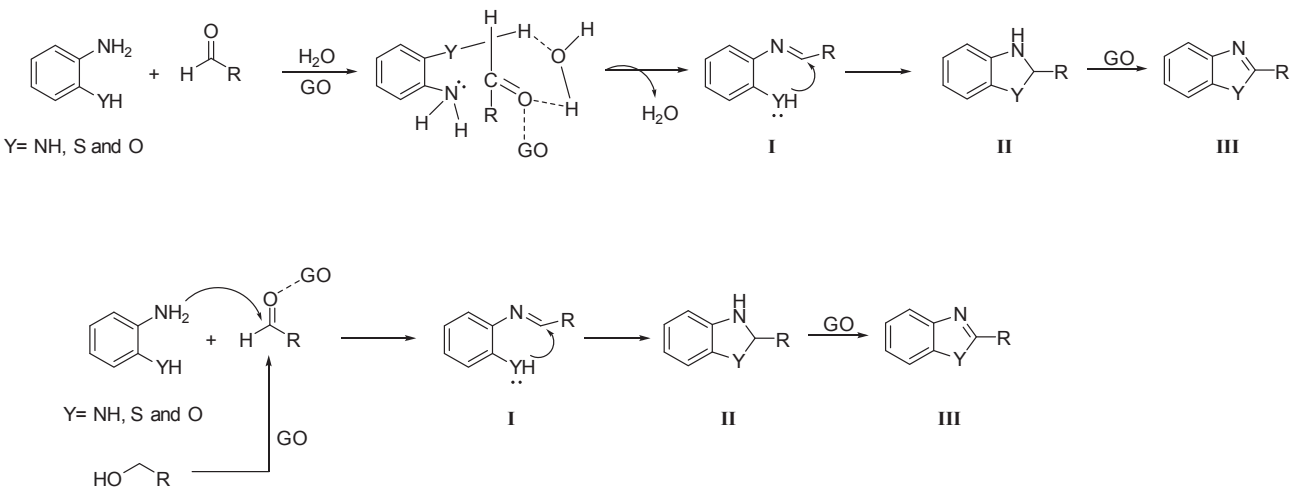


Figure 5. Proposed mechanism for the synthesis of benzazoles in the presence of GO.

sites in GO, we converted the carboxylic acid groups in GO into carboxylate groups by treating GO with base (NaOH, 1 M). After base treatment, it was found that the catalytic activity of GO was completely stopped. This confirmed that the carboxylic acid groups in the GO have a basic role in the catalysis reactions.

Conclusion

In summary, a simple and efficient procedure for facile preparation of benzazoles via the condensation of various aldehydes and *o*-substituted aminobenzene with GO in water is described. In addition, GO is explored as a heterogeneous bifunctional reagent for sequential oxidation and condensation reaction of alcohols with 2-amino(thio)phenol/aniline in PEG-200 to give their corresponding benzazoles. Our method is environmentally friendly, the easy work-up allowing the isolation of the final products in moderate to excellent yields and eliminates the use of a precious metal catalyst, toxic or expensive reagents and solvents. To the best of our knowledge, these results constitute the first report of application of GO with a simultaneous dual role in an organic transformation.

Experimental

Materials and Methods. All chemicals used in this study were analytical grade, commercially available and used without further purification. Most of the products were purified by column chromatography from appropriate solvents and were identified by ^{1}H NMR, ^{13}C NMR, and elemental analyses. Progress of the reactions was monitored by TLC using silica gel polygrams SIL G/UV 254 plates. FT-IR spectra were recorded on a Shimadzu DR-8001 spectrometer. NMR spectra were recorded on a Bruker Avance DPX 250 MHz instrument in $CDCl_3$ or DMSO-d_6 solvents using TMS as internal standard. Chemical shifts are reported in ppm (δ), and coupling constants (J), in Hz. Elemental analyses were determined in our department using a ThermoFinnigan Flash EA 1112 Series. The surface morphology of graphite and GO was analyzed by using field emission scanning electron microscopy (FESEM, SIGMA, ZEISS, Germany) and atomic force microscopy (AFM, DUALSCOPE^{TM} DS 95-50-E, DME, Denmark). The thermal stability of graphite and GO was investigated by thermogravimetric analysis (STA 503, Bahr, Germany) at a heating rate of 10 °C min^{-1} under N_2 flow (2 mL min^{-1}). X-ray diffraction (XRD) patterns were recorded on a XRD-D8 (BRUKER, Germany) employing a scanning rate of 0.05° s^{-1} from 10 to 90° with Cu Kα radiation. The absorbance of GO solutions was detected by a UV–vis Spectrophotometer (Pharmacia Biotech Ultraspec 4000). Dispersive Raman microscopy (SENTERRA, BRUKER, Germany) was used to characterize functional groups and structural information. The analysis system was equipped with high-energy laser diodes. Melting points were determined in open capillaries with a Galen-Kamp melting point apparatus and are not corrected.

Synthesis of GO. Natural flake graphite (1 g, particle size: <50 μm; from Merck), $NaNO_3$ (fine mesh, 1.0 g) and H_2SO_4 (48 mL, 98%) was cooled to 0 °C by stirring in an ice bath for 15 min. 3.0 g of finely meshed $KMnO_4$ powder was added slowly with vigorous stirring while keeping the temperature below 20 °C (a dark colored mixture was obtained). After 1.5 h, the mixture was warmed to 35 ± 3 °C for 30 min. Then 180 mL of water was added slowly, the temperature rose gradually and was kept at 95 °C for another 30 min. Then 400 mL of water was added. Finally aqueous solution of hydrogen peroxide (H_2O_2, 35%, 10 mL) was added to convert the unreacted permanganate and manganese dioxide into soluble sulfates. The vibrant yellow mixture was then filtered and the precipitate washed with an aqueous HCl solution (5%, 200 mL). The prepared GO was dialyzed in a dialysis bag for 1 week to ensure the complete removal of acid and residual metal ions. The final precipitate was kept in the dark until further use. For using in the reactions, the graphite oxide aqueous suspension was ultrasonicated (200 mL, 10 mg mL^{-1}) for 1 h to form GO.

General Procedure for the Synthesis of Benzimidazoles 2 from Aldehydes. A mixture of aldehyde (1 mmol) and *o*-phenylenediamine **1a** (1 mmol, 108.1 mg) in water (1 mL) were added to dispersed solution of GO (100 wt %, 108.7 mg) in water (2 mL) and the reaction mixture was stirred at 60 °C for appropriate time (Table 2). After completion of the reaction (monitored by TLC using *n*-hexane/EtOAc 9:1 as eluent), the GO was separated by filtration and the solution was extracted with ethyl acetate (2 × 5 mL). The GO was washed with warm ethanol (about 75 °C, 5 × 10 mL) and then organic layers (EtOAc and ethanol) were combined and dried over anhydrous sodium sulfate. The solvents were removed under reduced pressure and the residue left out was purified by chromatography on a short column of silica gel eluted with *n*-hexane/ethyl acetate (9:1) to give the corresponding benzimidazoles **2** in 78–95% yield (Table 2).

2-Phenyl-1*H*-benzimidazole (2a):[26a] White solid; yield: 174 mg (90%); mp >260 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 7.14–7.21 (m, 2H), 7.43–7.60 (m, 5H), 8.13–8.21 (m, 2H), 12.93 (br s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 151.2, 130.1, 129.8, 129.2, 128.9, 128.4, 126.4, 122.1. Anal. Calcd for $C_{13}H_{10}N_2$: C, 80.39; H, 5.19; N, 14.42%. Found: C, 80.58; H, 4.92; N, 14.50%.

2-(3-Nitrophenyl)-1*H*-benzimidazole (2b):[26c] Yellow solid; yield: 220 mg (92%); mp >260 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 7.20–7.22 (m, 2H), 7.74–7.83 (m, 3H), 8.23–8.32 (m, 1H), 8.52–8.57 (m, 1H), 8.94 (s, 1H), 13.24 (br s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 148.9, 148.2, 132.3, 131.5, 130.6, 124.1, 122.7, 120.7. Anal. Calcd for $C_{13}H_9N_3O_2$: C, 65.27; H, 3.79; N, 17.56%. Found: C, 65.09; H, 3.92; N, 17.50%.

2-(4-Nitrophenyl)-1*H*-benzimidazole (2c):[26b] Yellow solid; yield: 227 mg (95%); mp >260 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 7.24–7.26 (m, 2H), 7.56–7.58 (m, 2H), 8.34–8.46 (m, 4H), 13.13 (br s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 152.8, 141.2, 132.4, 129.0, 128.5, 127.3, 124.4, 116.7. Anal. Calcd for $C_{13}H_9N_3O_2$: C, 65.27; H, 3.79; N, 17.56%. Found: C, 65.41; H, 3.68; N, 17.67%.

2-(4-Cyanophenyl)-1*H*-benzimidazole (2d):[7c] White solid; yield: 204 mg (93%); mp 261–263 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 7.23–7.24 (m, 2H), 7.55–7.57 (m, 2H), 8.00 (d, J = 8.0 Hz, 2H), 8.32 (d, J = 8.0 Hz, 2H), 13.17 (br s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 149.3, 134.2, 132.9, 126.9, 123.3, 122.3, 119.2, 118.6, 111.8. Anal. Calcd for

$C_{14}H_9N_3$: C, 76.70; H, 4.14; N, 19.17%. Found: C, 76.61; H, 4.07; N, 19.32%.

2-(2-Chlorophenyl)-1*H*-benzimidazole (2e):[26b] White solid; yield: 189 mg (83%); mp 232–234 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 7.21–7.23 (m, 2H), 7.48–7.53 (m, 5H), 7.88–7.92 (m, 1H), 12.74 (br s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 149.3, 143.3, 134.7, 132.1, 131.8, 131.2, 130.2, 129.9, 127.3, 122.7, 121.8, 119.0, 111.8. Anal. Calcd for $C_{13}H_9ClN_2$: C, 68.28; H, 3.97; N, 12.25%. Found: C, 68.10; H, 3.85; N, 12.49%.

2-(4-Chlorophenyl)-1*H*-benzimidazole (2f):[26b] Yellow solid; yield: 200 mg (88%); mp >260 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 7.18–7.22 (m, 2H), 7.54–7.62 (m, 4H), 8.11–8.22 (m, 2H), 12.98 (br s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 150.0, 134.4, 129.0, 128.0, 122.6, 121.8, 118.8, 111.4. Anal. Calcd for $C_{13}H_9ClN_2$: C, 68.28; H, 3.97; N, 12.25%. Found: C, 68.42; H, 3.90; N, 12.11%.

2-(2-Pyridinyl)-1*H*-benzimidazole (2g):[21b] White solid; yield: 177 mg (91%); mp 217–219 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 7.18–7.23 (m, 2H), 7.49–7.67 (m, 3H), 7.97–7.98 (m, 1H), 8.30–8.34 (m, 1H), 8.71 (d, J = 6.8 Hz, 1H), 13.08 (br s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 150.6, 149.2, 148.4, 143.8, 137.4, 134.8, 124.7, 123.1, 121.8, 121.3, 119.2, 112.0. Anal. Calcd for $C_{12}H_9N_3$: C, 73.83; H, 4.65; N, 21.52%. Found: C, 73.68; H, 4.74; N, 21.58%.

2-(4-Methylphenyl)-1*H*-benzimidazole (2h):[26b] White solid; yield: 177 mg (85%); mp >260 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 2.34 (s, 3H), 7.17 (dd, J = 5.9, 3.0 Hz, 2H), 7.33 (d, J = 8.1 Hz, 2H), 7.54–7.56 (m, 2H), 8.04 (m, 2H), 12.85 (br s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 151.3, 139.5, 129.5, 128.8, 127.3, 126.3, 121.8, 20.8. Anal. Calcd for $C_{14}H_{12}N_2$: C, 80.74; H, 5.81; N, 13.45%. Found: C, 80.53; H, 6.11; N, 13.36%.

2-(4-Methoxyphenyl)-1*H*-benzimidazole (2i):[26b] Yellow solid; yield: 181 mg (81%); mp 228–230 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 3.82 (s, 3H), 7.11–7.17 (m, 4H), 7.49–7.52 (m, 2H), 8.07 (d, J = 8.1 Hz, 2H), 12.76 (br s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 161.5, 151.3, 128.0, 122.5, 122.0, 121.5, 118.4, 114.3, 111.0, 55.2. Anal. Calcd for $C_{14}H_{12}N_2O$: C, 74.98; H, 5.39; N, 12.49%. Found: C, 75.17; H, 5.51; N, 12.23%.

2-Methyl-1*H*-benzimidazole (2j):[7c] Light yellow solid; yield: 103 mg (78%); mp 175–177 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 2.68 (s, 3H), 7.15–7.22 (m, 2H), 7.49–7.53 (m, 2H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 153.1, 139.3, 123.1, 115.8, 13.8. Anal. Calcd for $C_8H_8N_2$: C, 72.70; H, 6.10; N, 21.20%. Found: C, 72.88; H, 6.01; N, 21.11%.

2-Phenyl-1,3-benzothiazole (4a):[26d] White solid; yield: 184 mg (87%); mp 112–114 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.38–7.50 (m, 5H), 7.88–7.90 (m, 1H), 8.08–8.12 (m, 3H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 168.0, 154.1, 135.0, 133.5, 130.9, 129.0, 127.5, 126.3, 125.2, 123.2, 121.6. Anal. Calcd for $C_{13}H_9NS$: C, 73.90; H, 4.29; N, 6.63%. Found: C, 74.14; H, 4.18; N, 6.78%.

2-(2-Chlorophenyl)benzothiazole (4b):[8b] White solid; yield: 194 mg (79%); mp 84–86 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.14–7.25 (m, 3H), 7.31–7.36 (m, 2H), 7.74 (d, J = 8.0 Hz, 1H), 8.00–8.08 (m, 2H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 164.0, 152.5, 136.1, 132.6, 130.8, 127.4, 126.3, 125.8, 125.4, 125.0, 123.4, 122.9, 121.4. Anal. Calcd for $C_{13}H_8ClNS$: C, 63.54; H, 3.28; N, 5.70%. Found: C, 63.39; H, 3.46; N, 5.84%.

2-(3-Chlorophenyl)benzothiazole (4c):[26e] Yellow solid; yield: 213 mg (87%); mp 96–98 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.18–7.37 (m, 4H), 7.70–7.76 (m, 2H), 7.91–7.94 (m, 2H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 166.2, 153.9, 135.1, 130.8, 129.2, 128.6, 127.8, 126.5, 125.6, 125.3, 123.4, 123.2, 121.6. Anal. Calcd for $C_{13}H_8ClNS$: C, 63.54; H, 3.28; N, 5.70%. Found: C, 63.50; H, 3.08; N, 5.92%.

2-(4-Chlorophenyl)benzothiazole (4d):[26f] White solid; yield: 216 mg (88%); mp 115–117 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.36–7.42 (m, 1H), 7.49–7.55 (m, 3H), 7.98 (d, J = 8.0 Hz, 1H), 8.08–8.12 (m, 3H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 166.3, 154.4, 137.0, 135.5, 132.3, 129.4, 128.5, 126.7, 124.0, 123.3, 121.8. Anal. Calcd for $C_{13}H_8ClNS$: C, 63.54; H, 3.28; N, 5.70%. Found: C, 63.68; H, 3.17; N, 5.46%.

2-(4-Bromophenyl)benzothiazole (4e):[26e] White solid; yield: 243 mg (84%); mp 132–134 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.33–7.43 (m, 4H), 7.70–7.75 (m, 3H), 7.91 (d, J = 8.1 Hz, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 166.6, 154.0, 135.0, 132.4, 131.7, 130.1, 128.8, 127.5, 126.4, 126.0, 125.1, 123.6, 121.6. Anal. Calcd for $C_{13}H_8BrNS$: C, 53.81; H, 2.78; N, 4.83%. Found: C, 53.98; H, 2.69; N, 4.92%.

2-(3-Hydroxyphenyl)benzothiazole (4f):[26g] Yellow solid; yield: 175 mg (77%); mp 169–171 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 7.02 (d, J = 7.6 Hz, 1H), 7.29–7.48 (m, 4H), 7.79 (d, J = 7.3 Hz, 1H), 7.95–8.04 (m, 2H), 9.99 (s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 167.3, 158.0, 153.5, 134.0, 131.1, 130.3, 126.9, 125.2, 124.4, 122.7, 122.0, 118.5, 113.5. Anal. Calcd for $C_{13}H_9NOS$: C, 68.70; H, 3.99; N, 6.16%. Found: C, 68.82; H, 3.83; N, 6.27%.

2-(4-Hydroxyphenyl)benzothiazole (4g):[26h] Yellow solid; yield: 163 mg (72%); mp 228–230 °C. ^{1}H NMR (250 MHz, DMSO-d_6): δ 6.98 (d, J = 8.5 Hz, 2H), 7.31 (t, J = 7.5 Hz, 1H), 7.43 (t, J = 7.9 Hz, 1H), 7.91–7.98 (m, 4H), 10.31 (s, 1H). ^{13}C NMR (62.9 MHz, DMSO-d_6): δ 167.4, 160.5, 159.8, 153.7, 134.1, 128.5, 126.2, 125.5, 124.7, 124.1, 123.5, 121.8, 117.3. Anal. Calcd for $C_{13}H_9NOS$: C, 68.70; H, 3.99; N, 6.16%. Found: C, 68.58; H, 4.11; N, 6.06%.

2-(2-Methylphenyl)benzothiazole (4h):[26f] Yellow solid; yield: 149 mg (66%); mp 56–58 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 2.80 (s, 3H), 7.38–7.50 (m, 4H), 7.56–7.60 (m, 1H), 7.88–7.96 (m, 2H), 8.26 (d, J = 8.1 Hz, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 168.0, 153.9, 137.3, 135.6, 133.1, 131.7, 131.0, 130.4, 130.0, 129.6, 126.2, 123.4, 120.9, 21.6. Anal. Calcd for $C_{14}H_{11}NS$: C, 74.63; H, 4.92; N, 6.22%. Found: C, 74.74; H, 4.85; N, 6.11%.

2-(4-Methylphenyl)benzothiazole (4i):[26f] White solid; yield: 153 mg (68%); mp 85–87 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 2.14 (s, 3H), 7.02 (d, J = 8.0 Hz, 2H), 7.08–7.14 (m, 1H), 7.22–7.28 (m, 1H), 7.60 (d, J = 8.0 Hz, 1H), 7.76 (d, J = 8.2 Hz, 1H), 7.89 (d, J = 8.0 Hz, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 165.7, 162.2, 152.2, 134.5, 126.5, 124.7, 124.4, 123.5, 121.6, 121.2, 120.7, 120.2, 18.9. Anal. Calcd for $C_{14}H_{11}NS$: C, 74.63; H, 4.92; N, 6.22%. Found: C, 74.45; H, 5.18; N, 6.36%.

2-(4-Methoxyphenyl)benzothiazole (4j):[26f] White solid; yield: 154 mg (64%); mp 121–123 °C. ^{1}H NMR (250 MHz,

$CDCl_3$): δ 3.70 (s, 3H), 6.83 (dd, $J = 8.8$, 2.0 Hz, 2H), 7.19–7.23 (m, 1H), 7.29–7.32 (m, 1H), 7.71 (d, $J = 7.9$ Hz, 1H), 7.86–7.91 (m, 3H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 167.8, 161.9, 154.1, 153.1, 136.6, 134.8, 129.1, 126.3, 124.7, 122.8, 121.5, 114.3, 113.5, 55.4. Anal. Calcd for $C_{14}H_{11}NOS$: C, 69.68; H, 4.59; N, 5.80%. Found: C, 69.51; H, 4.40; N, 6.04%.

2-Methylbenzothiazole (4k):[26f] Colorless oil; yield: 91 mg (61%). ^{1}H NMR (250 MHz, $CDCl_3$): δ 2.58 (s, 3H), 7.11–7.20 (m, 1H), 7.23–7.30 (m, 1H), 7.58–7.64 (m, 1H), 7.77–7.83 (m, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 168.2, 154.2, 141.3, 135.0, 131.0, 128.7, 123.6, 21.5. Anal. Calcd for C_8H_7NS: C, 64.40; H, 4.73; N, 9.39%. Found: C, 64.54; H, 4.60; N, 9.48%.

2-Eethylbenzothiazole (4l):[4a] Colorless oil; yield: 91 mg (56%). ^{1}H NMR (250 MHz, $CDCl_3$): δ 1.17 (t, $J = 7.6$ Hz, 3H), 2.85 (q, $J = 7.6$ Hz, 2H), 7.00–7.18 (m, 2H), 7.52 (d, $J = 7.9$ Hz, 1H), 7.72 (d, $J = 7.6$ Hz, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 173.4, 153.2, 135.0, 125.8, 124.5, 122.4, 121.4, 29.7, 13.7. Anal. Calcd for C_9H_9NS: C, 66.22; H, 5.56; N, 8.58%. Found: C, 66.13; H, 5.50; N, 8.79%.

2-Benzylbenzothiazole (4m):[26f] Yellow solid; yield: 155 mg (69%); mp 157–159 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 4.18 (s, 2H), 7.02–7.22 (m, 7H), 7.50 (d, $J = 7.9$ Hz, 1H), 7.82 (d, $J = 8.1$ Hz, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 171.1, 153.7, 137.2, 135.7, 131.3, 129.6, 129.0, 128.5, 127.4, 126.4, 126.0, 124.8, 121.6, 40.6. Anal. Calcd for $C_{14}H_{11}NS$: C, 74.63; H, 4.92; N, 6.22%. Found: C, 74.70; H, 5.05; N, 6.08%.

2-Phenyl-1,3-benzoxazole (6a):[26i] White solid; yield: 162 mg (83%); mp 121–123 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.19–7.22 (m, 2H), 7.36–7.41 (m, 4H), 7.60–7.67 (m, 1H), 8.11–8.15 (m, 2H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 163.0, 150.7, 142.0, 131.4, 128.8, 128.3, 127.6, 127.1, 125.0, 124.5, 120.0, 110.5. Anal. Calcd for $C_{13}H_9NO$: C, 79.98; H, 4.65; N, 7.17%. Found: C, 80.23; H, 4.73; N, 6.96%.

2-(2-Nitrophenyl)-1,3-benzoxazole (6b):[26j] Yellow solid; yield: 204 mg (85%); mp 105–107 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.38–7.47 (m, 2H), 7.64 (d, $J = 8.9$ Hz, 1H), 7.83 (d, $J = 8.6$ Hz, 1H), 8.36–8.46 (m, 4H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 165.9, 154.2, 137.9, 135.4, 132.7, 130.0, 128.5, 126.2, 125.0, 124.4, 121.6. Anal. Calcd for $C_{13}H_8N_2O_3$: C, 65.00; H, 3.36; N, 11.66%. Found: C, 65.32; H, 3.04; N, 11.44%.

2-(3-Nitrophenyl)-1,3-benzoxazole (6c):[26j] White solid; yield: 209 mg (87%); mp 210–212 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.39–7.42 (m, 2H), 7.61–7.82 (m, 3H), 8.37 (d, $J = 8.1$ Hz, 1H), 8.57 (d, $J = 7.6$ Hz, 1H), 9.08 (s, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 160.8, 151.8, 147.2, 140.9, 132.8, 130.3, 129.0, 125.9, 125.2, 124.7, 120.4, 118.1, 112.1. Anal. Calcd for $C_{13}H_8N_2O_3$: C, 65.00; H, 3.36; N, 11.66%. Found: C, 64.90; H, 3.21; N, 11.79%.

2-(2-Chlorophenyl)-1,3-benzoxazole (6d):[26i] White solid; yield: 184 mg (80%); mp 64–66 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.16–7.20 (m, 4H), 7.31–7.39 (m, 2H), 7.67 (d, $J = 5.9$ Hz, 1H), 7.92–7.96 (m, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 160.8, 150.4, 141.6, 133.3, 131.8, 130.0, 127.4, 126.8, 126.1, 125.5, 124.6, 120.4, 111.0. Anal. Calcd for $C_{13}H_8ClNO$: C, 67.99; H, 3.51; N, 6.10%. Found: C, 68.11; H, 3.43; N, 6.24%.

2-(3-Chlorophenyl)-1,3-benzoxazole (6e):[26i] White solid; yield: 172 mg (75%); mp 124–126 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.35–7.59 (m, 5H), 7.76–7.80 (m, 1H), 8.14 (d, $J = 7.1$ Hz, 1H), 8.25 (s, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 162.4, 150.4, 141.9, 135.0, 131.4, 130.2, 128.8, 127.5, 125.6, 125.5, 124.8, 120.2, 110.7. Anal. Calcd for $C_{13}H_8ClNO$: C, 67.99; H, 3.51; N, 6.10%. Found: C, 68.08; H, 3.69; N, 5.88%.

2-(4-Bromophenyl)-1,3-benzoxazole (6f):[26i] White solid; yield: 195 mg (71%); mp 158–160 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 7.30–7.35 (m, 2H), 7.51–7.61 (m, 3H), 7.71–7.75 (m, 1H), 8.05 (d, $J = 8.6$ Hz, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 162.0, 150.6, 141.9, 132.1, 128.9, 126.1, 126.0, 125.3, 124.7, 120.0, 110.6. Anal. Calcd for $C_{13}H_8BrNO$: C, 56.96; H, 2.94; N, 5.11%. Found: C, 56.80; H, 3.07; N, 5.24%.

2-(2-Hydroxyphenyl)-1,3-benzoxazole (6g):[26k] White solid; yield: 131 mg (62%); mp 122–124 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 6.90–6.96 (m, 1H), 7.10–7.13 (m, 1H). 7.34–7.50 (m, 3H), 7.64 (d, $J = 7.8$ Hz, 1H), 7.83 (d, $J = 7.8$ Hz, 1H), 7.95 (d, $J = 8.1$ Hz, 1H) 9.63 (s, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 162.8, 158.7, 149.0, 139.9, 133.5, 127.0, 125.3, 124.9, 119.5, 118.5, 117.3, 116.8, 110.6. Anal. Calcd for $C_{13}H_9NO_2$: C, 73.92; H, 4.30; N, 6.63%. Found: C, 73.87; H, 4.45; N, 6.54%.

2-(3-Hydroxyphenyl)-1,3-benzoxazole (6h):[26i] White solid; yield: 139 mg (66%); mp 230–232 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 6.99–7.02 (m, 1H), 7.32–7.40 (m, 3H), 7.67–7.73 (m, 4H), 10.02 (br s, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 167.4, 162.2, 158.1, 151.7, 150.0, 141.3, 130.3, 129.4, 127.4, 125.2, 120.5, 115.8, 110.7. Anal. Calcd for $C_{13}H_9NO_2$: C, 73.92; H, 4.30; N, 6.63%. Found: C, 73.80; H, 4.38; N, 6.59%.

2-(4-Hydroxyphenyl)-1,3-benzoxazole (6i):[26i] White solid; yield: 133 mg (63%); mp 255–257 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 6.96 (d, $J = 8.7$ Hz, 2H), 7.30 (dd, $J = 6.0$, 3.2 Hz, 2H), 7.62–7.69 (m, 2H), 8.02 (d, $J = 8.7$ Hz, 2H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 167.9, 166.1, 155.2, 146.9, 134.4, 134.0, 129.8, 129.6, 124.3, 122.3, 121.2, 116.1, 115.3. Anal. Calcd for $C_{13}H_9NO_2$: C, 73.92; H, 4.30; N, 6.63%. Found: C, 74.04; H, 4.19; N, 6.52%.

2-Methyl-1,3-benzoxazole (6j):[26i] Yellow oil; yield: 74 mg (56%). ^{1}H NMR (250 MHz, $CDCl_3$): δ 2.54 (s, 3H), 7.18–7.22 (m, 2H), 7.36–7.40 (m, 1H), 7.55–7.58 (m, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 163.2, 150.6, 141.3, 125.9, 124.9, 124.2, 119.4, 109.6.

2-Ethyl-1,3-benzoxazole (6k):[26i] Yellow oil; yield: 58 mg (39%). ^{1}H NMR (250 MHz, $CDCl_3$): δ 1.39 (t, $J = 7.6$ Hz, 3H), 2.89 (q, $J = 7.6$ Hz, 2H), 7.19–7.25 (m, 2H), 7.38–7.42 (m, 1H), 7.58–7.62 (m, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 168.1, 150.7, 141.2, 124.4, 124.0, 119.4, 110.2, 22.1, 10.8.

2-Benzyl-1,3-benzoxazole (6l):[26h] Yellow solid; yield: 92 mg (44%); mp 108–110 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ 4.28 (s, 2H), 7.27–7.46 (m, 8H), 7.72–8.03 (m, 1H). ^{13}C NMR (62.9 MHz, $CDCl_3$): δ 165.2, 151.0, 141.4, 134.8, 128.9, 127.6, 126.9, 125.9, 124.5, 121.1, 119.8, 110.4, 35.3.

General Procedure for the Synthesis of Benzimidazoles 2 from Alcohols in PEG-200. A 5 mL flask equipped with a stirrer bar was charged with the alcohol (1.2 mmol), GO (300 wt %) and 2 mL of PEG-200. The resulting mixture was heated at 110 °C until almost all alcohols were oxidized. After almost complete oxidation of the starting alcohol to aldehyde, 1 mmol of *o*-phenylenediamine **1a** was added and allow the reaction mixture to stir at 110 °C until the consumption of *o*-phenyl-

enediamine was completed (reaction monitored by TLC). Upon completion of the reaction, the reaction mixture was diluted with water and filtered through a sintered funnel to separate GO. The aqueous solution was extracted with ethyl acetate (2 × 5 mL). Then GO was washed with warm ethanol (5 × 10 mL). The combined organic phases (ethyl acetate and ethanol) were dried over anhydrous Na_2SO_4, sodium sulfate was filtered and the solvent was evaporated to obtain the product which was purified by column chromatography.

Partial financial support of this work by the research council of Shiraz University and helpful discussions with Prof. N. Iranpoor are acknowledged. We thank Dr. Hamid Ershadifar for providing UV–visible and CV (Cyclic Voltammetry) of GO and Dr. M. M Doroodmand for quantitative characterization of GO.

Supporting Information

FT-IR, UV–vis., Raman Spectrum, TGA curve, XRD, AFM, and SEM images of GO. This material is available electronically on J-STAGE.

References

1 a) X. Hui, J. Desrivot, C. Bories, P. M. Loiseau, X. Franck, R. Hocquemiller, B. Figadère, *Bioorg. Med. Chem. Lett.* **2006**, *16*, 815. b) C. Srinivas, C. N. S. S. P. Kumar, V. J. Rao, S. Palaniappan, *J. Mol. Catal. A: Chem.* **2007**, *265*, 227. c) R. N. Brown, R. Cameron, D. K. Chalmers, S. Hamilton, A. Luttick, G. Y. Krippner, D. B. McConnell, R. Nearn, P. C. Stanislawski, S. P. Tucker, K. G. Waston, *Bioorg. Med. Chem. Lett.* **2005**, *15*, 2051. d) K.-J. Soderlind, B. Gorodetsky, A. K. Singh, N. R. Bachur, G. G. Miller, J. W. Lown, *Anti-Cancer Drug Des.* **1999**, *14*, 19. e) A. A. Weekes, A. D. Westwell, *Curr. Med. Chem.* **2009**, *16*, 2430. f) M. Mader, A. de Dios, C. Shih, R. Bonjouklian, T. Li, W. White, B. L. de Uralde, C. Sánchez-Martinez, M. del Prado, C. Jaramillo, E. de Diego, L. M. Martín Cabrejas, C. Dominguez, C. Montero, T. Shepherd, R. Dally, J. E. Toth, A. Chatterjee, S. Pleite, J. Blanco-Urgoiti, L. Perez, M. Barberis, M. J Lorite, E. Jambrina, C. R. Nevill, Jr., P. A. Lee, R. C. Schultz, J. A. Wolos, L. C. Li, R. M. Campbell, B. D. Anderson, *Bioorg. Med. Chem. Lett.* **2008**, *18*, 179. g) K. F. Ansari, C. Lal, *Eur. J. Med. Chem.* **2009**, *44*, 2294. h) C. Jin, S. E. Fix, J. A. Kepler, C. E. Cook, *Bioorg. Med. Chem. Lett.* **2012**, *22*, 1705.

2 a) F. S. Rodembusch, T. Buckup, M. Segala, L. Tavares, R. R. B. Correia, V. Stefani, *Chem. Phys.* **2004**, *305*, 115. b) J.-R. Gong, L.-J. Wan, S.-B. Lei, C.-L. Bai, X.-H. Zhang, S.-T. Lee, *J. Phys. Chem. B* **2005**, *109*, 1675. c) T.-R. Chen, *J. Mol. Struct.* **2005**, *737*, 35.

3 a) Y. Kim, M. R. Kumar, N. Park, Y. Heo, S. Lee, *J. Org. Chem.* **2011**, *76*, 9577. b) S. Murru, B. K. Patel, J. L. Bras, J. Muzart, *J. Org. Chem.* **2009**, *74*, 2217. c) D. Yang, H. Fu, L. Hu, Y. Jiang, Y. Zhao, *J. Org. Chem.* **2008**, *73*, 7841. d) S. Gupta, P. K. Agarwal, B. Kundu, *Tetrahedron Lett.* **2010**, *51*, 1887. e) P. J. Boissarie, Z. E. Hamilton, S. Lang, J. A. Murphy, C. J. Suckling, *Org. Lett.* **2011**, *13*, 6256. f) R. D. Viirre, G. Evindar, R. A. Batey, *J. Org. Chem.* **2008**, *73*, 3452. g) J. Peng, M. Ye, C. Zong, F. Hu, L. Feng, X. Wang, Y. Wang, C. Chen, *J. Org. Chem.* **2011**, *76*, 716. h) V. N. Bochatay, P. J. Boissarie, J. A. Murphy, C. J. Suckling, S. Lang, *J. Org. Chem.* **2013**, *78*, 1471. i) J. E. R. Sadig, R. Foster, F. Wakenhut, M. C. Willis, *J. Org. Chem.* **2012**, *77*, 9473.

4 a) M. S. Mayo, X. Yu, X. Zhou, X. Feng, Y. Yamamoto, M. Bao, *Org. Lett.* **2014**, *16*, 764. b) Z.-X. Wang, H.-L. Qin, *J. Heterocycl. Chem.* **2005**, *42*, 1001.

5 a) S. Kamila, H. Zhang, E. R. Biehl, *Heterocycles* **2005**, *65*, 2119. b) L. Cai, X. Ji, Z. Yao, F. Xu, Q. Shen, *Chin. J. Chem.* **2011**, *29*, 1880.

6 a) S. Kamila, B. Koh, E. R. Biehl, *J. Heterocycl. Chem.* **2006**, *43*, 1609. b) D.-F. Shi, T. D. Bradshaw, S. Wrigley, C. J. McCall, P. Lelieveld, I. Fichtner, M. F. G. Stevens, *J. Med. Chem.* **1996**, *39*, 3375. c) D. W. Hein, R. J. Alheim, J. J. Leavitt, *J. Am. Chem. Soc.* **1957**, *79*, 427. d) V. K. Tandon, M. Kumar, *Tetrahedron Lett.* **2004**, *45*, 4185. e) K. R. Kumar, P. V. V. Satyanarayana, B. S. Reddy, *J. Chem.* **2013**, 151273. f) M. Terashima, M. A. Ishii, Y. Kanaoka, *Synthesis* **1982**, 484. g) A. K. Chakraborti, S. Rudrawar, G. Kaur, L. Sharma, *Synlett* **2004**, 1533.

7 a) H. Leutbecher, M.-A. Constantin, S. Mika, J. Conrad, U. Beifuss, *Tetrahedron Lett.* **2011**, *52*, 605. b) S. M. Inamdar, V. K. More, S. K. Mandal, *Tetrahedron Lett.* **2013**, *54*, 579. c) C. Mukhopadhyay, P. K. Tapaswi, *Tetrahedron Lett.* **2008**, *49*, 6237. d) R. Chebolu, D. N. Kommi, D. Kumar, N. Bollineni, A. K. Chakraborti, *J. Org. Chem.* **2012**, *77*, 10158. e) A. Kumar, R. A. Maurya, P. Ahmad, *J. Comb. Chem.* **2009**, *11*, 198. f) Y.-X. Chen, L.-F. Qian, W. Zhang, B. Han, *Angew. Chem., Int. Ed.* **2008**, *47*, 9330. g) K. Yamaguchi, T. Noda, Y. Higuchi, N. Aoki, R. Yamaguchi, M. Kubo, K. Harada, Y. Fukuyama, H. Hioki, *Tetrahedron Lett.* **2014**, *55*, 5793. h) Y. Nagasawa, Y. Matsusaki, T. Hotta, T. Nobuta, N. Tada, T. Miura, A. Itoh, *Tetrahedron Lett.* **2014**, *55*, 6543. i) H. Sharma, N. Singh, D. O. Jang, *Green Chem.* **2014**, *16*, 4922.

8 a) Y. Wang, K. Sarris, D. R. Sauer, S. W. Djuric, *Tetrahedron Lett.* **2006**, *47*, 4823. b) X. Wen, J. E. Bakali, R. Deprez-Poulain, B. Deprez, *Tetrahedron Lett.* **2012**, *53*, 2440. c) Y.-H. So, J. P. Heeschen, *J. Org. Chem.* **1997**, *62*, 3552. d) S. Rudrawar, A. Kondaskar, A. K. Chakraborti, *Synthesis* **2005**, 2521. e) A. K. Chakraborti, C. Selvam, G. Kaur, S. Bhagat, *Synlett* **2004**, 851. f) R. Kumar, C. Selvam, G. Kaur, A. K. Chakraborti, *Synlett* **2005**, 1401. g) D. Kumar, S. Rudrawar, A. K. Chakraborti, *Aust. J. Chem.* **2008**, *61*, 881.

9 a) A. K. Geim, K. S. Novoselov, *Nat. Mater.* **2007**, *6*, 183. b) C. Lee, X. Wei, J. W. Kysar, J. Hone, *Science* **2008**, *321*, 385. c) Y. Zhang, Y.-W. Tan, H. L. Stormer, P. Kim, *Nature* **2005**, *438*, 201. d) A. A. Balandin, S. Ghosh, W. Bao, I. Calizo, D. Teweldebrhan, F. Miao, C. N. Lau, *Nano Lett.* **2008**, *8*, 902. e) S. Park, R. S. Ruoff, *Nat. Nanotechnol.* **2009**, *4*, 217.

10 a) W. S. Hummers, Jr., R. E. Offeman, *J. Am. Chem. Soc.* **1958**, *80*, 1339. b) D. Li, R. B. Kaner, *Science* **2008**, *320*, 1170.

11 D. R. Dreyer, H.-P. Jia, C. W. Bielawski, *Angew. Chem., Int. Ed.* **2010**, *49*, 6813.

12 a) D. R. Dreyer, S. Park, C. W. Bielawski, R. S. Ruoff, *Chem. Soc. Rev.* **2010**, *39*, 228. b) T. Szabó, E. Tombácz, E. Ellés, I. Dékány, *Carbon* **2006**, *44*, 537.

13 D. R. Dreyer, H.-P. Jia, A. D. Todd, J. Geng, C. W. Bielawski, *Org. Biomol. Chem.* **2011**, *9*, 7292.

14 a) M. Mahyari, A. Shaabani, *Appl. Catal., A* **2014**, *469*, 524. b) M. Mirza-Aghayan, E. Kashef-Azar, R. Boukherroub, *Tetrahedron Lett.* **2012**, *53*, 4962.

15 H.-P. Jia, D. R. Dreyer, C. W. Bielawski, *Tetrahedron* **2011**, *67*, 4431.

16 M. Mirza-Aghayan, R. Boukherroub, M. Nemati, M. Rahimifard, *Tetrahedron Lett.* **2012**, *53*, 2473.

17 a) B. Basu, S. Kundu, D. Sengupta, *RSC Adv.* **2013**, *3*, 22130. b) Y. Kim, S. Some, H. Lee, *Chem. Commun.* **2013**, *49*, 5702. c) A. Dhakshinamoorthy, M. Alvaro, P. Concepción, V.

Fornés, H. Garcia, *Chem. Commun.* **2012**, *48*, 5443. d) H. Wang, T. Deng, Y. Wang, X. Cui, Y. Qi, X. Mu, X. Hou, Y. Zhu, *Green Chem.* **2013**, *15*, 2379. e) S. Verma, H. P. Mungse, N. Kumar, S. Chouhary, S. L. Jain, B. Sain, O. P. Khatri, *Chem. Commun.* **2011**, *47*, 12673. f) A. V. Kumar, K. R. Rao, *Tetrahedron Lett.* **2011**, *52*, 5188. g) H.-P. Jia, D. R. Dreyer, C. W. Bielawski, *Adv. Synth. Catal.* **2011**, *353*, 528. h) X. Gao, S. Zhu, Y. Li, *Catal. Commun.* **2015**, *62*, 48. i) S. Kumari, A. Shekhar, H. P. Mungse, O. P. Khatri, D. D. Pathak, *RSC Adv.* **2014**, *4*, 41690. j) B. Roy, D. Sengupta, B. Basu, *Tetrahedron Lett.* **2014**, *55*, 6596. k) C. Su, R. Tandiana, J. Balapanuru, W. Tang, K. Pareek, C. T. Nai, T. Hayashi, K. P. Loh, *J. Am. Chem. Soc.* **2015**, *137*, 685. l) M. Mirza-Aghayan, M. Alizadeh, M. Molaee Tavana, R. Boukherroub, *Tetrahedron Lett.* **2014**, *55*, 6694. m) J. Huang, S. Ding, W. Xiao, Y. Peng, S. Deng, N. Zhang, *Catal. Lett.* **2015**, *145*, 1000.

18 M. R. Karim, K. Hatakeyama, T. Matsui, H. Takehira, T. Taniguchi, M. Koinuma, Y. Matsumoto, T. Akutagawa, T. Nakamura, S. Noro, T. Yamada, H. Kitagawa, S. Hayami, *J. Am. Chem. Soc.* **2013**, *135*, 8097.

19 a) Z. Liu, Q. Liu, Y. Huang, Y. Ma, S. Yin, X. Zhang, W. Sun, Y. Chen, *Adv. Mater.* **2008**, *20*, 3924. b) H. A. Becerril, J. Mao, Z. Liu, R. M. Stoltenberg, Z. Bao, Y. Chen, *ACS Nano* **2008**, *2*, 463. c) S. Guo, G. Zhang, Y. Guo, J. C. Yu, *Carbon* **2013**, *60*, 437. d) X. Hu, L. Mu, J. Wen, Q. Zhou, *Carbon* **2012**, *50*, 2772. e) J. I. Paredes, S. Villar-Rodil, A. Martínez-Alonso, J. M. D. Rascón, *Langmuir* **2008**, *24*, 10560.

20 a) S. Stankovich, D. A. Dikin, R. D. Piner, K. A. Kohlhaas, A. Kleinhammes, Y. Jia, Y. Wu, S. T. Nguyen, R. S. Ruoff, *Carbon* **2007**, *45*, 1558. b) O. C. Compton, S. T. Nguyen, *Small* **2010**, *6*, 711.

21 a) K. Selvam, M. Swaminathan, *Chem. Lett.* **2007**, *36*, 1060. b) G. Li, J. Wang, B. Yuan, D. Zhang, Z. Lin, P. Li, H. Huang, *Tetrahedron Lett.* **2013**, *54*, 6934. c) K. D. Parghi, R. V. Jayaram, *Catal. Commun.* **2010**, *11*, 1205. d) V. R. Ruiz, A. Corma, M. J. Sabater, *Tetrahedron* **2010**, *66*, 730. e) A. R. Momeni, H. A. Samimi, R. Jahanian, *Iran. J. Catal.* **2012**, *2*, 141.

22 a) B. Li, A.-H. Liu, L.-N. He, Z.-Z. Yang, J. Gao, K.-H. Chen, *Green Chem.* **2012**, *14*, 130. b) A. Haimov, R. Neumann, *Chem. Commun.* **2002**, 876. c) J. Chen, S. K. Spear, J. G. Huddleston, R. D. Rogers, *Green Chem.* **2005**, *7*, 64. d) A. R. Hajipour, G. Azizi, *Green Chem.* **2013**, *15*, 1030. e) J. Yu, M. Shen, M. Lu, *J. Iran. Chem. Soc.* **2015**, *12*, 771.

23 a) D. Lanari, O. Rosati, M. Curini, *Tetrahedron Lett.* **2014**, *55*, 1752. b) B. Lesch, J. Töräng, S. Vanderheiden, S. Bräse, *Adv. Synth. Catal.* **2005**, *347*, 555. c) A. Nagaraju, B. J. Ramulu, G. Shukla, A. Srivastava, G. K. Verma, K. Raghuvanshi, M. S. Singh, *Green Chem.* **2015**, *17*, 950. d) R. Tadikonda, M. Nakka, S. Rayavarapu, S. P. K. Kalidindi, S. Vidavalur, *Tetrahedron Lett.* **2015**, *56*, 690. e) A. V. H. Rao, P. N. K. Babu, V. L. Rao, A. J. Shree, *Asian. J. Chem.* **2015**, *27*, 1910.

24 a) A. K. Chakraborti, S. Rudrawar, K. B. Jadhav, G. Kaur, S. V. Chankeshwara, *Green Chem.* **2007**, *9*, 1335. b) V. K. Aggarwal, D. K. Dean, A. Mereu, R. Williams, *J. Org. Chem.* **2002**, *67*, 510.

25 A. Sengupta, C. Su, C. Bao, C. T. Nai, K. P. Loh, *ChemCatChem* **2014**, *6*, 2507.

26 a) G. Brasche, S. L. Buchwald, *Angew. Chem., Int. Ed.* **2008**, *47*, 1932. b) G. Bai, X. Lan, X. Liu, C. Liu, L. Shi, Q. Chen, G. Chen, *Green Chem.* **2014**, *16*, 3160. c) M. Abdollahi-Alibeik, M. Moosavifard, S. Poorirani, *Synth. React. Inorg., Met.-Org., Nano-Met. Chem.* **2013**, *43*, 1365. d) D. Rambabu, P. R. K. Murthi, B. Dulla, M. V. B. Rao, M. Pal, *Synth. Commun.* **2013**, *43*, 3083. e) Z. Yang, X. Chen, S. Wang, J. Liu, K. Xie, A. Wang, Z. Tan, *J. Org. Chem.* **2012**, *77*, 7086. f) H. Yu, M. Zhang, Y. Li, *J. Org. Chem.* **2013**, *78*, 8898. g) H. Sharghi, O. Asemani, *Synth. Commun.* **2009**, *39*, 860. h) A. Khalafi-Nezhad, F. Panahi, R. Yousefi, S. Sarrafi, Y. Gholamalipour, *J. Iran. Chem. Soc.* **2014**, *11*, 1311. i) A. Khalafi-Nezhad, F. Panahi, *ACS Catal.* **2014**, *4*, 1686. j) S. Zhao, Y. Chen, Y.-F. Song, *Appl. Catal., A* **2014**, *475*, 140. k) Y. H. Cho, C.-Y. Lee, D.-C. Ha, C.-H. Cheon, *Adv. Synth. Catal.* **2012**, *354*, 2992.