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Heteropolyacids as Green and Reusable Catalysts for the Synthesis of 3,1,5-Benzoxadiazepines

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Abstract: Synthesis of 3,1,5-benzoxadiazepines from the condensation of *o*-phenylenediamine (*o*-PDA) and acyl chlorides in the presence of a catalytic amount of various heteropolyacids (HPAs) is reported.

Keywords: 3,1,5-Benzoxadiazepines, recyclable catalysts, heteropolyacids, heterocycle.

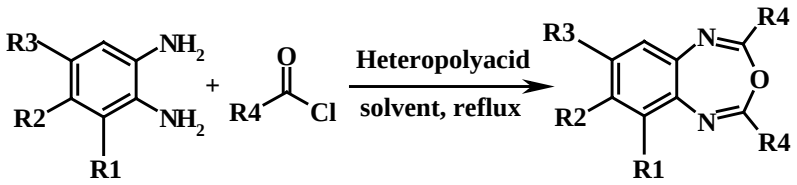
Introduction

Heteropolyacids (HPAs) are well defined molecular clusters that are remarkable for their molecular and electronic structural diversity and their quite diverse significance in many areas, e.g., catalysis, medicine, and materials science [1-2].

The applications of heteropolyacids, HPAs, in the field of catalysis are growing continuously. These compounds possess unique properties such as Brönsted acidity, possibility to modify their acid-base and redox properties by changing their chemical composition (substituted HPAs), ability to accept and release electrons, high proton mobility, easy work-up procedures, easy filtration, and minimization of cost and waste generation due to reuse and recycling of these catalysts [3-7]. Because of their stronger acidity, they generally exhibit higher catalytic activity than conventional catalysts such as mineral acids, ion exchange resins, mixed oxides, zeolites, etc. [8]. In the context of Green Chemistry, the substitution of harmful liquid acids by solid reusable HPAs as catalysts in organic synthesis is the most promising application of these acids [9,10].

Benzoxadiazepines have been found to possess marked biological effects as CNS stimulants. They have also been reported as antibacterial and anti-inflammatory agents, pesticides and insecticides [11]. Few methods are reported in the literature for the synthesis of benzoxadiazepines [12-14]. During the course of our studies towards the development of HPAs as efficient heterogeneous catalysts [15-18] herein we wish to report the synthesis of 3,1,5-benzoxadiazepines derivatives by cyclization of *o*-PDA and acyl chlorides in the presence of a catalytic amount of various type of HPAs, including $H_{14}[NaP_5W_{30}O_{110}]$, $H_5[PMo_{10}V_2O_{40}]$ and $H_6[P_2W_{18}O_{62}]$. (Scheme1).

Scheme 1.



Results and Discussion

Due to the ever-mounting environmental concern in the field of chemistry, it is advisable to use easily recovered and recycled catalysts, especially expensive or toxic metallic ones [19]. In this respect, only few of the aforementioned catalysts meet this Green Chemistry criterion.

In connection with our program of using heteropolyacids in organic reactions [20] we wish to report the results of a study on the use of three type of HPAs, including Preyssler, $H_{14}[NaP_5W_{30}O_{110}]$, Keggin, $H_4[PMo_{11}VO_{40}]$ and Wells-Dawson types $H_6[P_2W_{18}O_{62}]$ in the synthesis of 3,1,5-benzoxadiazepines and the effects of reaction parameters such as the type of HPA, temperature and reaction times on the reaction yields.

The results indicate that the nature of the catalyst plays an important role on their catalytic activities. As shown in Table 1, $H_{14}[NaP_5W_{30}O_{110}]$ showed the highest activity and gave better yields.

Table 1. Synthesis of 3,1,5-benzoxadiazepines derivatives using various heteropolyacids under refluxing conditions.

Entry	R_1	R_2	R_3	R_4	Catalyst	Yield %[a]
1	H	H	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	80
2	H	H	H	CH_3	$H_6[P_2W_{18}O_{62}]$	74.8
3	H	H	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	60
4	H	CH_3	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	85.7
5	H	CH_3	H	CH_3	$H_6[P_2W_{18}O_{62}]$	78.25
6	H	CH_3	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	61

a) Yields were analyzed by GC.

Preyssler's anion, $[NaP_5W_{30}O_{110}]^{14-}$, has an approximate D_5h symmetry and consists of a cyclic assembly of five PW_6O_{22} units. A sodium ion is located within the polyanion on the fivefold axis and 1.25 above the pseudo mirror plane that contains the five phosphorus atoms [21]. Preyssler polyanion

as a large anion can provide many ‘‘sites’’ on the oval-shaped molecule that are likely to render the catalyst effective.

The Keggin anions have an assembly of 12 corner-shared octahedral MoO_6 from trimetallic groups $[Mo_3O_{13}]$ around a heteroatom tetrahedron PO_4. The introduction of vanadium (V) into the Keggin framework of $[PMo_{12}O_{40}]^{3-}$ is beneficial for catalysis reactions. Usually positional isomers are possible and coexist when two or more vanadium atoms are incorporated into the Keggin structure. Studies on these isomers in catalytic reactions indicate that different isomers cause to show different reactivities.

With respect to the catalytic performance of these catalysts and the overall effects of all isomers, we cannot control the reaction conditions for the synthesis of positional vanadium-substituted isomers separately, indicating that the relationship between the $H_{3+x}PMo_{12-x}VxO_{40}$ (x = 1) structures and hence study of their catalytic activity is difficult. However, because the metal substitution may modify the energy and composition of the LUMO and redox properties, for mentioned heteropolyacids with different charges, the energy and composition of the LUMOs have significant effects on the catalytic activity. Substitution of vanadium ions into the molybdenum framework stabilize the LUMOs because these orbitals derive, in part, from vanadium d-orbitals which have been assumed to be more stable than those of molybdenum and tungsten [22]. The abundance of different isomers may also play an important role in catalytic performance. In addition, different positional Mo atom(s) substituted by the V atom(s) in $[PMo_{12}O_{40}]^{3-}$ may create different vanadium chemical environments, thus causing these catalysts to exhibit varying catalytic performances. Considering the above explanations we suggest that the rigidity, steric hindrance and lower number of protons in $H_4[PMo_{11}VO_{40}]$ are tentatively assumed to be responsible for its observed lower activity. The larger number of protons may lower the activation barrier to the reaction.

As noted from the data in Table 1, electron-donating groups on *o*-PDA increased the yield of the reactions. The effect of temperature was studied by carrying out the reactions at different temperatures [room temperature, 25°C, 50°C and under refluxing temperature (82°C)]. As shown in Table 2, the reaction yields increased as the reaction temperature was raised. From these results, it was decided that refluxing temperature would be the best temperature for all reactions.

For investigation of the best reaction time the reaction yields were studied at different times (0.5, 1, 2, 3, 4h). The results indicate that in each reaction, the yield is a function of the reaction time and the best time for all reactions was optimized to be 4h.

When 4-nitrophenylenediamine, 3,5-dinitrophenylenediamine and benzoyl chloride were used as substrates in this reaction the corresponding benzodimidazoles were obtained instead of 3,1,5-benzoxadiazepines (Scheme 2).

Scheme 2.

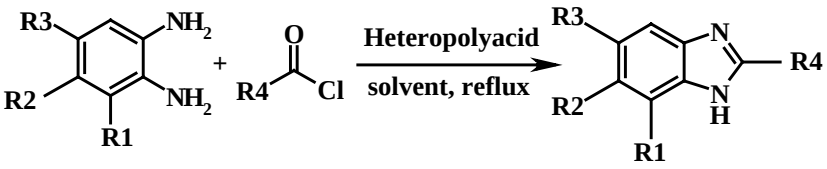


Table 2. Effect of different reaction time and temperature on synthesis of 3,1,5-benzoxadiazepines derivatives using various heteropolyacids.

Entry	R_1	R_2	R_3	R_4	Catalyst	Time (h)	Yield%[a]		
							25°C	50°C	82°C
1	H	H	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	0.5	41	44	50
2	H	H	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	1	50	55	59
3	H	H	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	2	56	60	65
4	H	H	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	3	67	69	74
5	H	H	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	4	73	77	80
6	H	H	H	CH_3	$H_6[P_2W_{18}O_{62}]$	0.5	38	43	48
7	H	H	H	CH_3	$H_6[P_2W_{18}O_{62}]$	1	47	51	55
8	H	H	H	CH_3	$H_6[P_2W_{18}O_{62}]$	2	54	59	63
9	H	H	H	CH_3	$H_6[P_2W_{18}O_{62}]$	3	59	67	68
10	H	H	H	CH_3	$H_6[P_2W_{18}O_{62}]$	4	65	70	74.8
11	H	H	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	0.5	23	27	29
12	H	H	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	1	29	33	37
13	H	H	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	2	33	38	42
14	H	H	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	3	46	49	53
15	H	H	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	4	53	57	60
16	H	CH_3	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	0.5	44	52	58
17	H	CH_3	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	1	52	59	63
18	H	CH_3	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	2	61	67	71
19	H	CH_3	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	3	60	69	76
20	H	CH_3	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	4	66	72	85.7
21	H	CH_3	H	CH_3	$H_6[P_2W_{18}O_{62}]$	0.5	39	42	48
22	H	CH_3	H	CH_3	$H_6[P_2W_{18}O_{62}]$	1	48	52	57
23	H	CH_3	H	CH_3	$H_6[P_2W_{18}O_{62}]$	2	55	59	64
24	H	CH_3	H	CH_3	$H_6[P_2W_{18}O_{62}]$	3	64	68	70
25	H	CH_3	H	CH_3	$H_6[P_2W_{18}O_{62}]$	4	70	72	78.25
26	H	CH_3	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	0.5	22	30	36
27	H	CH_3	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	1	29	35	40
28	H	CH_3	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	2	35	41	48
29	H	CH_3	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	3	49	51	53
30	H	CH_3	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	4	57	59	61

a) Yields were analyzed by GC.

The products were characterized using ^{1}H-NMR and IR spectroscopy and GC–MS analysis. Analytical data were in accord with those reported for authentic samples.

The results are summarized in Table 3. It is presumed that the amine group *meta* to the NO_2 group participated in the reaction, while the amine groups *para* or *ortho* to the nitro could not participate because the latter are considered to be powerful electron withdrawing groups and may reduce the nucleophilicity of the amine. In the case of benzoyl chloride the steric effect of phenyl groups prevent the formation of 3,1,5-benzoxadiazepines.

Table 3. Synthesis of benzimidazole derivatives using various heteropolyacids under refluxing conditions.

Entry	R_1	R_2	R_3	R_4	Catalyst	Yield %[a]
1	H	NO_2	H	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	98.5
2	H	NO_2	H	CH_3	$H_6[P_2W_{18}O_{62}]$	97
3	H	NO_2	H	CH_3	$H_5[PMo_{10}V_2O_{40}]$	95.7
4	H	NO_2	H	C_6H_5	$H_{14}[NaP_5W_{30}O_{110}]$	98
5	H	NO_2	H	C_6H_5	$H_6[P_2W_{18}O_{62}]$	94
6	H	NO_2	H	C_6H_5	$H_5[PMo_{10}V_2O_{40}]$	85
7	NO_2	H	NO_2	CH_3	$H_{14}[NaP_5W_{30}O_{110}]$	97
8	NO_2	H	NO_2	CH_3	$H_6[P_2W_{18}O_{62}]$	95.7
9	NO_2	H	NO_2	CH_3	$H_5[PMo_{10}V_2O_{40}]$	90.4
10	NO_2	H	NO_2	C_6H_5	$H_{14}[NaP_5W_{30}O_{110}]$	85.7
11	NO_2	H	NO_2	C_6H_5	$H_6[P_2W_{18}O_{62}]$	78.2
12	NO_2	H	NO_2	C_6H_5	$H_5[PMo_{10}V_2O_{40}]$	77.3

[a] yields are analyzed by GC

As shown in Table 3, the reaction yields for the synthesis of benzimidazole derivaties are high. Thus, heteropolyacids can be used as efficient catalysts for the synthesis of benzimidazoles, especially for derivatives with electron withdrawing groups (such as nitro groups). The more electron withdrawing groups present the lower the yields obtained were. On the other hand, the steric effect of phenyl groups also reduced the yield of reactions. The same trend of catalyst efficiency was observed for this reaction. Thus the same explanation could be applied here.

Experimental

General

All chemicals were obtained from Merck and used as received. $H_{14}[NaP_5W_{30}O_{110}]$ was prepared according to earlier reports [8,16,4]. $H_4[PMo_{11}VO_{40}]$ and $H_5[PMo_{10}V_2O_{40}]$ were prepared according to the literature [22]. The Wells-Dawson species $H_6[P_2W_{18}O_{62}]$ was prepared as described elsewhere [23], from an aqueous solution of α/β $K_6P_2W_{18}O_{62}\cdot 10H_2O$ salt, which was treated with ether and concentrated (37%) HCl solution. GC–MS analyses were performed on a GC–MS system consisting of an Agilent 5973 network mass selective detector and a model 6890 GC. IR spectra were obtained with a Buck Scientific 500 spectrometer. ^{1}H-NMR spectra were recorded on a Bruker 90 MHz FT-NMR.

General Procedure

o-PDA (6 mmol) was dissolved in acetonitrile (10 mL) and acyl chloride (12 mmol) was added to the solution, followed by the catalyst (0.1 mmol). The reaction mixture was heated at reflux temperature for 4 h. The progress of the reaction was monitored by TLC using 1:2 EtOAc-hexane as eluent. After completion of the reaction, the catalyst was filtered off and the solvent was evaporated. The pure products were obtained by column chromatography. All products were identified by comparison of their physical and spectroscopic data with those reported for authentic samples.

Spectral data for selected samples

2,4-Dimethyl-3,1,5-benzoxadiazepine (Table 1, Entry 1): IR (KBr/υ): 1673 (C=N), 1042 (C-O-C) cm^{-1}; ^{1}H-NMR ($CDCl_3$): 7.2 (m, 4H, Ar-H), 2.2 (s, 6H, CH_3); MS: m/z 174 [M^+].

6-Nitro-2-methyl-1H-benzimidazole (Table 3, Entry 1): IR (KBr/υ): 1604 (C=N), 1355 (NO_2), 3261 (NH) cm^{-1}; ^{1}H-NMR spectra ($CDCl_3$): 7.7 -8.0 (m, 3H, Ar-H), 2.4 (s, 3H, N=C-CH_3), 4 (br. s, 1H, N-H); MS: m/z 177 [M^+].

6-Nitro-2-phenyl-1H-benzimidazole (Table 3 Entry 4): IR (KBr/υ): 1604 (C=N), 1355 (NO_2), 3261 (NH) cm^{-1}; ^{1}H-NMR ($CDCl_3$): 7.6 -8.4 (m, 3H, Ar-H), 7.3-8.1 (m, 5H, N=C-C_6H_5), 4.5 (br. s, 1H, N-H); MS: m/z 239 [M^+].

5,7-Dinitro-2-methyl-1H-benzimidazole (Table 3, Entry 7): IR (KBr/υ): 1604 (C=N), 1355-1400 (NO_2), 3261 (NH) cm^{-1}; ^{1}H-NMR ($CDCl_3$): 8 (s, 1H, Ar-H), 8.7 (s, 1H, Ar-H), 2.58 (s, 3H, N=C-CH_3), 4 (br. s, 1H, N-H); MS: m/z 222 [M^+].

5,7-Dinitro-2-phenyl-1H-benzimidazole (Table 3, Entry 10): IR (KBr/υ): 1604 (C=N), 1355-1400 (NO_2), 3261 (NH) cm^{-1}; ^{1}H-NMR ($CDCl_3$): 8 (s, 1H, Ar-H), 8.7 (s, 1H, Ar-H), 7.3-8 (m, 5H, N=C-C_6H_5), 4.5 (br. s, 1H, N-H); MS: m/z 284 [M^+].

Catalyst reusability

At the end of the reaction, the catalyst could be recovered by a simple filtration. The recycled catalyst could be washed with dichloromethane and used in a second run of the reaction process. The results of the first and subsequent experiments were almost consistent in yields.

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References

1. Misono, M.; Ono, L.; Koyano, G.; Aoshima, A. Heteropolyacids. Versatile green catalysts usable in a variety of reaction media. *Pure Appl. Chem*. **2000**, *72*, 1305-1311.
2. Pope, M.T.; Muller, A. *Polyoxometalates: from Platonic Solids to Anti-Retroviral Activity*; Kluwer Academic Publishers: Dordrecht, The Netherlands, **1994**.
3. Heravi, M. M.; Rajabzadeh, G.**;** Bamoharram, F. F.; Seifi, N. An eco-friendly catalytic route for synthesis of 4-amino-pyrazolo[3,4-d]pyrimidine derivatives by Keggin heteropolyacids under classical heating and microwave irradiation . *J. Mol. Catal. A: Chem.,* **2006**, *256*, 238-241.
4. Heravi, M. M.; Bakhtiari, Kh.; Bamoharram, F. F. An efficient and chemoselective synthesis of acylals from aromatic aldehydes and their regeneration, catalyzed by 12-molybdophosphoric acid. *Catal. Commun.* **2006**, *7*, 499-501.
5. Heravi, M. M.; Bamoharram, F. F.; Rajabzadeh, G.; Seifi, N.; Khatami, M. Preyssler heteropolyacid $[NaP_5W_{30}O_{110}]$14-, as a new, green and recyclable catalyst for the synthesis of [1,2,4]triazino[4,3-b][1,2,4,5]tetrazines . *J. Mol. Catal. A: Chem.* **2006,** 259, 213-217.
6. Pope, M.T. *Heteropoly and Isopoly Oxometalates*; Springer: Berlin, **1983**.
7. Heravi, M. M.; Bakhtiari, K.; Bamoharram. F. F. 12-Molybdophosphoric acid: A recyclable catalyst for the synthesis of Biginelli-type 3,4-dihydropyrimidine-2(1H)-ones. *Catal. Commun.* **2006**, *7*, 373-376.
8. Bamoharram, F. F.; Heravi, M. M.; Roshani, M.; Gharib, A.; Jahangir, M. A catalytic method for synthesis of γ-butyrolactone, ε-caprolactone and 2-cumaranone in the presence of Preyssler's anion, $[NaP_5W_{30}O_{110}]^{14-}$, as a green and reusable catalyst. *J. Mol. Catal. A: Chem.* **2006**, *252*, 90-95.
9. Heravi, M. M.; Motamedi, R.; Seifi, N.; Bamoharram. F. F. Catalytic synthesis of 6-aryl-1H-pyrazolo[3,4-d]pyrimidin-4[5H]-ones by heteropolyacid: $H_{14}[NaP_5W_{30}O_{110}]$ and $H_3PW_{12}O_{40}$. *J. Mol. Catal. A: Chem.* **2006**, *249*, 1-3.
10. Bamoharram, F. F.; Heravi, M. M.; Roshani, M.; Akbarpour, M. Catalytic performance of Preyssler heteropolyacid as a green and recyclable catalyst in oxidation of primary aromatic amines. *J. Mol. Catal. A: Chem.* **2006**, *255*,193-198.
11. Tandon, V. K.; Kumar, M. BF_3Et_2O promoted one-pot expeditious and convenient synthesis of 2-substituted benzimidazoles and 3,1,5-benzoxadiazepines. *Tetrahedron Lett.* **2004**, 45, 4185- 4187.
12. Mazurkiewicz, R. Novel synthesis and rearrangement of 3,1,5-benzoxadiazepines. *Monatsh. Chem.* **1988**, *119*, 1279-1287.
13. Sulkowski, T. S.; Childress, S.J. The formation and subsequent rearrangement of 7-Chloro-5-phenyl-3,1,4-benzoxadiazepine2(1H)-one. *J. Org. Chem.* **1962**, *27*, 4424-4426.
14. Sternbach, L.H.; Kaiser, S.; Reeder, E. Quinazoline 3-Oxide Structure of Compounds Previously Described in the Literature as 3,1,4-benzoxadiazepines. *J. Am. Chem. Soc.* **1960**, *82*, 475-480.
15. Bamoharram, F. F.; Heravi, M. M.; Roshani, M.;Tavakoli, N. N-oxidation of pyridine carboxylic acids using hydrogen peroxide catalyzed by a green heteropolyacid catalyst: Preyssler's anion, $[NaP_5W_{30}O_{110}]^{14-}$. *J. Mol. Catal. A: Chem.* **2006**, *252*, 219-225.

16. Bamoharram, F. F.; Heravi, M. M.; Roshani, M.; Jahangir, M.; Gharib, A. Preyssler catalyst, $[NaP_5W_{30}O_{110}]^{14-}$: A green, efficient and reusable catalyst for esterification of salicylic acid with aliphatic and benzylic alcohols**.** *J. Appl. Catal. A: Gen.l* **2006**, *302*, 42-47.
17. Heravi, M. M.; Behbahani, F. K.; Bamoharram. F. F. $H_{14}[NaP_5W_{30}O_{110}]$: A heteropolyacid catalyzed acetylation of alcohols and phenols in acetic anhydride. *J. Mol. Catal. A: Chem.* **2006**, *253*,16-19.
18. Heravi, M. M.; Ranjbar, L.; Derikvand, F.; Bamoharram, F. F. $H_6P_2W_{18}O_{62}$: An efficient and reusable catalyst for one-pot synthesis of β-acetamido ketone and esters. *Catal. Commun.* **2007**, *8*, 289-291.
19. Anastas, P. T.; Warner, J.C. *Green Chemistry: Theory and Practice*; Oxford University: Oxford, UK, **1998**.
20. Oskooie, H. A.; Heravi, M. M.; Bakhtiari, K.; Zadsirjan, V.; Bamoharram, F. F. $H_{14}[NaP_5W_{30}O_{110}]$ as an efficient catalyst for the one-pot synthesis of alpha-amino nitriles. *Synlett* **2006**, *11*, 1768-1770.
21. Heravi, M. M.; Zadsirjan, V.; Bakhtiari, K.; Oskooie, H. A. Bamoharram, F. F. Green and reusable heteropolyacid catalyzed oxidation of benzylic, allylic and aliphatic alcohols to carbonyl compounds. *Catal. Commun.* **2007**, *8*, 315-318.
22. Heravi, M. M.; Benmord. T.; Bakhtiari, K.; Bamoharram, F. F.; Oskooie, H. A. H3+*x*PMo12-*x*V*x*O40(heteropolyacids)-catalyzed regioselective nitration of phenol to *o*-nitrophenol in heterogeneous system. *J. Mol. Catal. A: Chem.* **2006**, *264*, 318-321.
23. Romanelli, G.; Autino, J.C.; Baronetti, G.; Thomas, H. Efficient Deprotection of Phenol Methoxymethyl Ethers Using a Solid Acid Catalyst with Wells-Dawson Structure. *Molecules* **2001,** 6, 1006-1011.

Sample Availability: Samples of the compounds presented in this paper are available from authors.