



# Aluminum dodecatungstophosphate (AlPW<sub>12</sub>O<sub>40</sub>) as an efficient heterogeneous inorganic catalyst for the chemoselective synthesis of geminal diacetates (acylals) under solvent-free conditions

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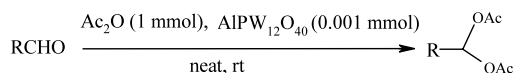
**Abstract**—An efficient and chemoselective preparation of acylals from structurally different aldehydes in the presence of AlPW<sub>12</sub>O<sub>40</sub> and acetic anhydride was achieved easily in high yields at room temperature under solvent-free conditions. © 2003 Elsevier Science Ltd. All rights reserved.

Heteropolyacids (HPAs) as catalysts for fine organic synthetic processes have been developed for industries related to fine chemicals, such as the flavors, pharmaceuticals and food industries.<sup>1</sup> Heteropolyacids are more active catalysts than conventional inorganic and organic acids for reactions in solution.<sup>2</sup> They are used as industrial catalysts for several liquid-phase reactions,<sup>3–6</sup> including alcohol dehydration,<sup>7</sup> alkylation,<sup>8</sup> and esterification.<sup>9</sup> Among heteropolyacids, polytungstic acids are the most widely used catalysts owing to their high acid strengths, thermal stabilities, and low reducibilities. Catalysts based on heteropolyacids have many advantages over liquid acid catalysts. They are non-corrosive and environmentally benign and present fewer disposal problems. Their repeated use is possible and their separation from liquid products is easier than for homogeneous catalysts.<sup>10</sup>

Acylals (*geminal* diacetates) or *gem*-bis (acyloxy)-alkanes have been used as protecting groups for carbonyl compounds because of their stability in neutral and basic media,<sup>11a</sup> as well as towards aqueous acids.<sup>11b</sup> Due to the remarkable stability of *gem* diacetates towards a variety of reactions, they play an important role in organic synthesis for the protection of aldehydes. In the last decade various catalysts have reported for their synthesis.<sup>12</sup> Reactions of acylals are also important for the preparation of other compounds and have been under investigation recently.<sup>13</sup>

Solvent-free reactions have attracted considerable attention in chemical processes due to their safety, economy, easy work up, high yields and usually fast reaction rates.<sup>14</sup> We have recently initiated studies into new catalytic properties of heteropoly acids, especially tungstophosphoric acid (H<sub>3</sub>PW<sub>12</sub>O<sub>40</sub>) as a cheap, reusable, heterogeneous and easily available catalyst. We have used catalytic amounts of this compound for the oxidation of aromatic amines to nitro compounds with sodium perborate in micellar media,<sup>15a</sup> for thioacetalization and transthoacetalization reactions,<sup>15b</sup> and its cesium salt for the regioselective brominating of aromatic compounds<sup>15c</sup> and selective *O*-trimethylsilylation of a wide variety of alcohols and phenols using hexamethyldisilazane (HMDS) under solvent-free conditions<sup>15d</sup> and the solvent-free oxidation of hydroxy groups with Fe(NO<sub>3</sub>)<sub>3</sub> activated by H<sub>3</sub>PW<sub>12</sub>O<sub>40</sub>.

The preparation of aluminum dodecatungstophosphate (AlPW<sub>12</sub>O<sub>40</sub>) was reported in 1982 by Ono using the reaction of aluminum nitrate and dodecatungstophosphoric acid in a quantitative yield.<sup>16</sup> We have prepared this compound by the addition of aluminum nitrate or by aluminum carbonate to an aqueous solution of tungstophosphoric acid which on complete evaporation of water gave the desired compound as a white powder in a quantitative yield. AlPW<sub>12</sub>O<sub>40</sub> prepared by both procedures gave satisfactory analytical results within



Scheme 1.

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**Table 1.** AlPW<sub>12</sub>O<sub>40</sub>-catalyzed formation of *gem*-diacetates from aldehydes

| Entry | Substrates                         | Time (min) | Yield (%) <sup>a</sup> | Ref. 12        |
|-------|------------------------------------|------------|------------------------|----------------|
| 1     | Benzaldehyde                       | 2          | 89                     | l,n,k,i,g,j    |
| 2     | 4-Me-Benzaldehyde                  | 1          | 96                     | j,k,n,l,i,g    |
| 3     | 4-Cl-Benzaldehyde                  | 6          | 95                     | i,j,n,k        |
| 4     | 2-Cl-Benzaldehyde                  | 5          | 91                     | n              |
| 5     | 3-MeO-benzaldehyde                 | 4          | 93                     | p              |
| 6     | Anisaldehyde                       | 6          | 90                     | j,g,o,k,j      |
| 7     | 3-NO <sub>2</sub> -Benzaldehyde    | 3          | 88 <sup>b</sup>        | k,b            |
| 8     | 4-NO <sub>2</sub> -Benzaldehyde    | 45         | 89 <sup>b</sup>        | j,l,i,n        |
| 9     | 4-CN-Benzaldehyde                  | 20         | 88 <sup>b</sup>        | n,b            |
| 10    | 2,6-Dichlorobenzaldehyde           | 15         | 95                     | — <sup>c</sup> |
| 11    | Heptanal                           | 12         | 92                     | l,i            |
| 12    | Cinnamaldehyde                     | 5          | 92                     | l,g,j          |
| 13    | 4-N(Me) <sub>2</sub> -benzaldehyde | 30         | 0 <sup>c</sup>         | —              |
| 14    | Furfural                           | 30         | 0 <sup>d</sup>         | —              |

<sup>a</sup> Isolated yields and the purity of the products were determined by <sup>1</sup>H NMR and GC.

<sup>b</sup> Reactions were carried out in 2 mL CH<sub>2</sub>Cl<sub>2</sub>.

<sup>c</sup> Reaction did not occur even under heating.

<sup>d</sup> An unidentified polymer was produced at 0°C.

<sup>e</sup> Spectral data are given in Ref. 19.

experimental error. This salt is a water stable and a non-hygroscopic compound. There is a report available in the literature, which deals with the conversion of methanol into hydrocarbons using this compound as a catalyst.<sup>17</sup>

Very recently we have used AlPW<sub>12</sub>O<sub>40</sub> for the selective and efficient acetylation of -OH, -NH<sub>2</sub>, and -SH in the presence of acetic anhydride.<sup>18</sup> Now we report that the efficient and chemoselective preparation of acylals<sup>18</sup> from structurally different aldehydes in the presence of this catalyst and acetic anhydride was achieved easily at room temperature under solvent-free conditions<sup>19</sup> (Scheme 1).

By using this catalyst, both activated and deactivated aromatic aldehydes were converted to their correspond-

ing diacetates in excellent yields (Table 1, entries 1–10). Aliphatic as well as  $\alpha,\beta$ -unsaturated aldehydes also gave the corresponding acylals in good yields under similar reaction conditions (Table 1, entries 11, 12). We found that this catalyst was not suitable for the preparation of acylals from aldehydes carrying amino groups (Table 1, entry 13). We have also attempted the acylation of furfural at different temperatures. In all runs, a dark colored unidentified polymeric material was obtained (Table 1, entry 14).

In order to show the merit of the present work in comparison with recently reported protocols, we compared the results of the *gem*-diacetate synthesis from cinnamaldehyde and 4-methylbenzaldehyde in the presence of metal triflates InCl<sub>3</sub>, NBS, LiBF<sub>4</sub> and AlPW<sub>12</sub>O<sub>40</sub> with respect to the amounts of the catalysts used, reaction times and yields of the products (Table 2). The results show that AlPW<sub>12</sub>O<sub>40</sub> promotes the reactions more effectively than InCl<sub>3</sub>, NBS, Cu(OTf)<sub>2</sub> and Sc(OTf)<sub>3</sub> as far as the amount of catalyst and reaction times are concerned. Reactions in the presence of LiBF<sub>4</sub> required higher temperatures with longer reaction times using an equal molar ratio. Bi(OTf)<sub>3</sub> catalysis was performed in CH<sub>3</sub>CN and at room temperature but the reaction times and also the yields of the products were lower than those obtained with AlPW<sub>12</sub>O<sub>40</sub>.

In order to show the high selectivity of the method, we studied competitive reactions for the acylation of aldehydes in the presence of ketones using AlPW<sub>12</sub>O<sub>40</sub> as the catalyst under solvent-free conditions at room temperature. Using this catalytic system, the highly selective conversion of aldehydes in the presence of ketones was observed. We also studied the acylation of 4-methylbenzaldehyde versus 4-nitrobenzaldehyde and 3-nitrobenzaldehyde in the presence of 4-nitrobenzaldehyde. These reactions also proceeded with high selectivity in the presence of this catalyst showing the importance of electronic effects upon these reactions in the presence of this catalyst (Table 3).

In conclusion, we have introduced a new mild and effective catalyst for the preparation of acylals from aldehydes in the presence of acetic anhydride at room

**Table 2.** Comparison of the effect of catalysts for *gem*-diacetate synthesis from cinnamaldehyde and 4-methylbenzaldehyde

| Entry | Catalyst                           | Cat. (mol%)         | Time <sup>a</sup> | Yield <sup>a</sup> | Time <sup>b</sup> | Yield <sup>b</sup> | Ref. |
|-------|------------------------------------|---------------------|-------------------|--------------------|-------------------|--------------------|------|
| 1     | InCl <sub>3</sub>                  | 10                  | 1 h               | 91                 | 1 h               | 96                 | 12n  |
| 3     | NBS                                | 20                  | 48 h              | 80                 | 9 h <sup>c</sup>  | 93                 | 12j  |
| 6     | LiBF <sub>4</sub>                  | 0.1/16 <sup>d</sup> | 16 h              | 86                 | 24 h <sup>d</sup> | 92                 | 12l  |
|       |                                    | 5 equiv.            | 4.5 h             | 90                 | —                 | —                  | 12o  |
| 5     | Cu(OTf) <sub>2</sub>               | 2.5                 | 3 h               | 76                 | 2 h               | 98                 | 12i  |
| 2     | Sc(OTf) <sub>3</sub>               | 2                   | 2 h               | 76                 | 10 min            | 95                 | 12g  |
| 7     | Bi(OTf) <sub>3</sub> <sup>c</sup>  | 0.1                 | 15 min            | 70                 | 30 min            | 87                 | 12k  |
| 8     | AlPW <sub>12</sub> O <sub>40</sub> | 0.1                 | 5 min             | 92                 | 1 min             | 96                 | —    |

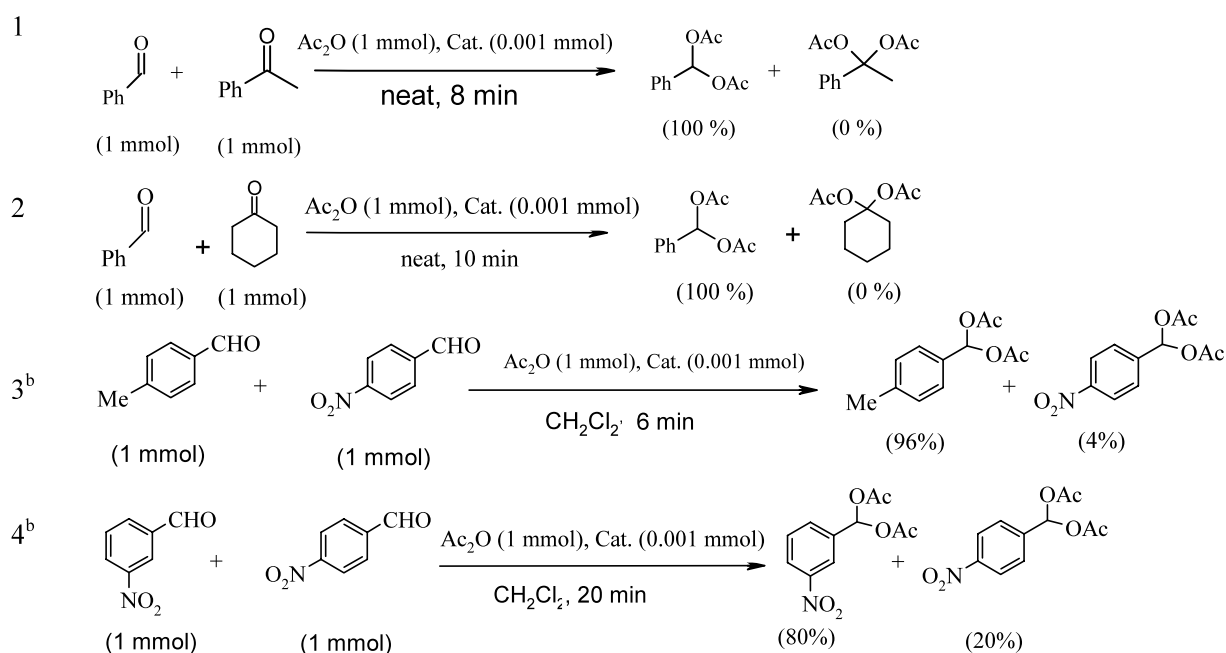
<sup>a</sup> Times and yields refer to *gem*-diacetate synthesis from cinnamaldehyde.

<sup>b</sup> Times and yields refer to *gem*-diacetate synthesis from 4-methylbenzaldehyde.

<sup>c</sup> CH<sub>3</sub>CN was used as a solvent.

<sup>d</sup> Reaction was carried out at 40°C.

<sup>e</sup> 10 mol% of catalyst was used.

**Table 3.** Competitive acylal formation of aldehydes using Ac<sub>2</sub>O in the presence of AlPW<sub>12</sub>O<sub>40</sub> at room temperature under solvent-free conditions<sup>a</sup>

a) The percentage of the products in the reaction mixtures was determined by GC analysis. b) Products were separated by prep. TLC in *n*-Hexane: EtOAc (8:2)

temperature in high yields. The method is highly selective for the sole preparation of acylals from aldehydes in the presence of ketones. AlPW<sub>12</sub>O<sub>40</sub> can be prepared from cheap and commercially available chemicals in a quantitative yield in aqueous media. In contrast to many other Lewis acids, storage of this compound does not need special precautions, e.g. it can be stored on a bench top for months without losing its catalytic activity. In addition, as a non-hygroscopic, non-corrosive and a water stable compound, the handling of AlPW<sub>12</sub>O<sub>40</sub> is easy which makes this catalyst suitable for the large-scale operations.

Applications of this new catalytic system to Diels–Alder, Friedel–Crafts and condensation reactions, and Beckmann and Fries rearrangements are under study in our laboratories.

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19. **Typical procedure for the preparation of acylals from 2,6-dichlorobenzaldehyde.** To a solution of 2,6-dichlorobenzaldehyde (5 mmol, 0.88 g) and freshly distilled acetic anhydride (5 mmol, 0.46 mL),  $\text{AlPW}_{12}\text{O}_{40}$  (0.015 g, 0.005 mmol) was added at room temperature. The reaction mixture was magnetically stirred for 15 min (monitored by TLC and GC). The resulting mixture was diluted with  $\text{Et}_2\text{O}$  (10 mL) and filtered. The filter cake was washed with  $\text{Et}_2\text{O}$  (2×5 mL) and the ethereal solutions were combined together and washed with a saturated solution of  $\text{NaHCO}_3$  (10 mL) and water (2×10 mL). The organic phase was dried over anhydrous  $\text{Na}_2\text{SO}_4$ , filtered and the solvent was evaporated to give the pure desired compound as a white crystalline compound (1.31 g, 95%), mp = 88.5°C.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ , TMS)  $\delta$  (ppm): 2.07 (s, 6H), 7.01 (t, 1H), 7.35 (d,  $J$  = 7.24 Hz, 2H), 8.62 (s, 1H).  $^{13}\text{C}$  NMR  $\delta$  (ppm): 168.56, 135.62, 131.01, 129.37, 87.61, 20.7. IR (KBr): 3080 (C–H ( $\text{OAc}$ )<sub>2</sub>), 1772 (C=O) and 1257 (O–COMe)  $\text{cm}^{-1}$ .