

Short communication

# Ruthenium(III) Chloride as an Efficient Catalyst for Conversion of Aldehydes to 1,1-diacetates Under Mild Conditions

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## Abstract

Ruthenium(III) chloride catalyzes the preparation of 1,1-diacetates from aldehydes under mild and in solvent or solvent-free conditions. This method has some advantages such as good to excellent yields, ease of operation and workup, short reaction time, high catalytic efficiency and high chemoselectivity.

**Keywords:** 1,1-diacetates, acylals, protecting group, ruthenium(III) chloride, aldehyde, solvent-free condition

## 1. Introduction

Geminal diacetates (acylals) are stable under neutral and basic conditions<sup>1</sup> and they are frequently used as protecting groups for aldehydes.<sup>2</sup> 1,1-Diacetates are synthetically important precursors for the preparation of 1-acetoxy dienes for Diels–Alder reaction.<sup>3</sup> The acyloxy groups in acylals can be converted into other useful functional groups by reaction with appropriate nucleophiles.<sup>4–5</sup> Recently, palladium-catalyzed asymmetric allylic alkylation of acylals was applied for the total synthesis of saphingofungins E and F.<sup>6</sup> In addition, indium-mediated allylations of gem-diacetates and palladium-catalyzed substitution reactions of geminal allylic diacetates have also been reported.<sup>7</sup>

Several reagents or catalysts such as InBr<sub>3</sub>,<sup>8</sup> Cu(OTf)<sub>2</sub>,<sup>9</sup> NBS,<sup>10</sup> Bi(NO<sub>3</sub>)<sub>3</sub> · 5H<sub>2</sub>O,<sup>11</sup> In(OTf)<sub>3</sub>,<sup>12</sup> Bi(OTf)<sub>3</sub> · x H<sub>2</sub>O,<sup>13</sup> zirconium sulfophenyl phosphonate,<sup>14</sup> H<sub>2</sub>NSO<sub>3</sub>H,<sup>15</sup> LiBF<sub>4</sub>,<sup>16</sup> zinc-Montmorillonite,<sup>17</sup> Zn(OTf)<sub>2</sub> · 6H<sub>2</sub>O,<sup>18</sup> sulfated zirconia<sup>19</sup> and heteropolycompounds such as Wells–Dawson acid,<sup>20</sup> P<sub>2</sub>O<sub>5</sub>/Al<sub>2</sub>O<sub>3</sub>,<sup>21</sup> HClO<sub>4</sub> · SiO<sub>2</sub>,<sup>22</sup> erbium triflate<sup>23</sup> and 12-molybdophosphoric acid<sup>24</sup> have been employed for the synthesis of acylals from aldehydes using acetic anhydride.

Ruthenium(III) chloride has been used as a catalyst for oxidation of tertiary amines,<sup>25</sup> alcohols<sup>26–28</sup> and phosphorous acid.<sup>29</sup> Recently, this catalyst was applied for the synthesis of 2-ethyl-3-methylquinolines from anilines and trialkylamine<sup>30</sup> and for acylation of alcohols, phenols, thiols and amines.<sup>31</sup>

In this work, we wish to report a mild, facile and efficient method for conversion of aldehydes to corresponding acylals using acetic anhydride in the presence of catalytic amounts of ruthenium(III) chloride hydrate without solvent or in *n*-hexane at room temperature.

## 2. Experimental

**General:** Starting materials and ruthenium(III) chloride were purchased from Fluka, Merck and Aldrich. The diacetate products were characterized by their spectral (IR, <sup>1</sup>H-NMR), TLC and physical data. IR spectra (KBr pellets) were recorded on Bruker Equinox 55 FTIR spectrometer. NMR spectra were obtained on a Bruker Avans 400 MHz or Hitachi-Perkin Elmer, R-24B, 60 MHz.

**Typical procedure for preparation of 1,1-diacetoxy-1-(2,6-dichlorophenyl)methane from 2,6-dichloro-**

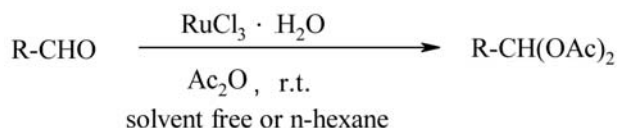
**benzaldehyde:** In a mortar, a mixture of 2,6-dichlorobenzaldehyde (0.525 g, 3 mmol), acetic anhydride (0.6 mL, 6 mmol), and  $\text{RuCl}_3 \cdot x\text{H}_2\text{O}$  (0.018 g) was pulverized for 5 minutes. The reaction progress was followed by TLC (eluent: chloroform). After 5 minutes of pulverization, the conversion was above 99%. After completion of the reaction, silica gel (1.5 g) and chloroform (24 mL) were added to the mixture and filtered. The solvent was evaporated to give the pure product as a white solid. The solid was recrystallized from a mixture of ethanol and water. Yield: 0.71 g (87%), m.p.: 88–89 °C. [Lit<sup>21</sup> m.p.: 88–89 °C].

### 3. Results and Discussion

At the beginning, in order to evaluate various Lewis acids as potential catalysts in the acylal formation, we have investigated their efficiency in a model reaction between acetic anhydride (6 mmol) and 3-nitrobenzaldehyde (3 mmol) at room temperature under grinding conditions. Among the screened catalysts,  $\text{RuCl}_3 \cdot x\text{H}_2\text{O}$  was found to be superior (Table 1, entry 14). It seems that not only the Lewis acidity of  $\text{RuCl}_3 \cdot x\text{H}_2\text{O}$  is stronger than that of other catalysts used, but also for the conversion the necessary amount of  $\text{RuCl}_3 \cdot x\text{H}_2\text{O}$  can be lesser than that of other catalysts. On the other hand, unfortunately, this very active catalyst is not reusable due to its high absorbency potential.

For a demonstration of the generality and ability of this catalyst, a variety of aliphatic and aromatic aldehydes were converted into acylals using catalytic amount of ruthenium(III) chloride hydrate (Scheme 1, Table 2). All products were known and characterized by their spectral data

(IR, <sup>1</sup>H-NMR and MS) and by comparison to the authentic samples. The results reveal that ruthenium(III) chloride catalyzed reactions generally result in good yields with aromatic aldehydes incorporating electron-withdrawing substituents. It is important to mention that other methods such as  $\text{AlPW}_{12}\text{O}_{40}$ -catalyzed reactions<sup>35</sup> have provided poor yields in the presence of electron withdrawing substituents.



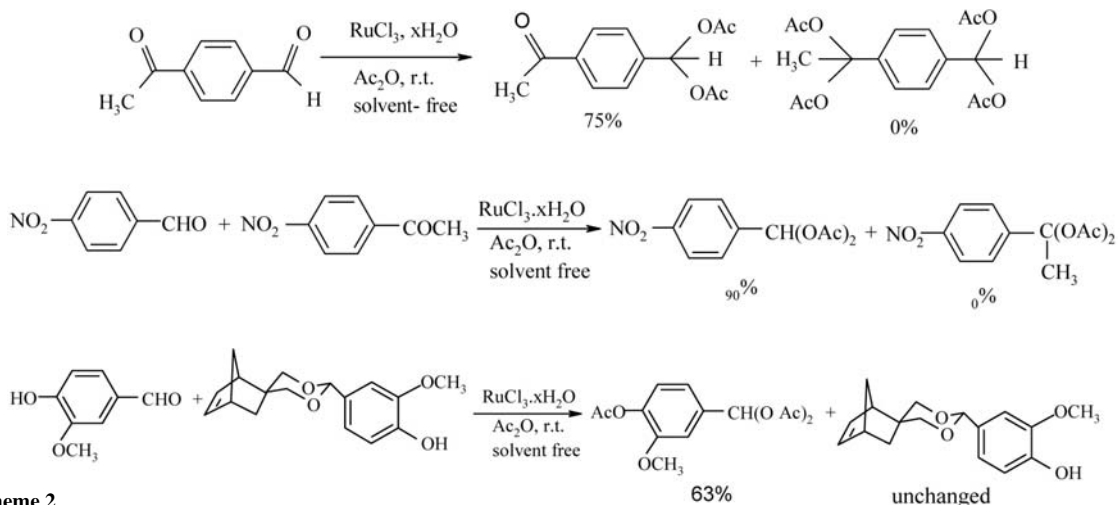
Scheme 1

Cyclohexanone, 4-nitroacetophenone and 4-acetylbenzaldehyde were also checked for the reactivity. The keto groups of these compounds have not reacted neither under room temperature nor reflux conditions. We suggest that the chemoselective protection of aldehydes in the presence of ketones can be achieved by this method (Scheme 2).

However, 4-(*N,N*-dimethylamino)benzaldehyde failed to give the expected acylal under grinding condition at room temperature or under reflux. The explanation for this result may be due to the strong electron donating properties of the dimethylamino group which will reduce the reactivity. It should be stressed that phenolic group was also protected as acetate in hydroxyl containing aromatic aldehyde (Table 2, entries 8 and 15) under such conditions.

Table 1: Conversion of 3-nitrobenzaldehyde to corresponding acylal by various catalysts.

entry	catalyst	condition/solvent	yield (%)
1	75% $\text{P}_2\text{O}_5/\text{SiO}_2$ (0.45 g) <sup>32</sup>	r.t., grinding	75
2	$\text{Zr}(\text{HSO}_4)_4$ (4 mol %) <sup>33</sup>	r.t., grinding	86
3	$\text{Al}(\text{HSO}_4)_3$ (5 mol %) <sup>34</sup>	r.t., grinding	80
4	$\text{FeCl}_3$ (40 mol %)	r.t., grinding	70
5	$\text{AlCl}_3$ (40 mol %)	r.t., grinding	75
6	$\text{ZnCl}_2$ (40 mol %)	r.t., grinding	64
7	$\text{SnCl}_4$ (40 mol %)	r.t., grinding	72
8	$\text{SbCl}_5$ (40 mol %)	r.t., grinding	75
9	$\text{BF}_3 \cdot \text{Et}_2\text{O}$ (40 mol %)	r.t., grinding	62
10	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.03 g)	r.t., grinding	89
11	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.025 g)	r.t., grinding	90
12	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.022 g)	r.t., grinding	90
13	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.02 g)	r.t., grinding	88
14	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.018 g)	r.t., grinding	88
15	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.015 g)	r.t., grinding	80
16	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.013 g)	r.t., grinding	78
17	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.01 g)	r.t., grinding	70
18	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.018 g)	reflux/n-hexane	67
19	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.018 g)	reflux/ $\text{CH}_2\text{Cl}_2$	56
20	$\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.018 g)	reflux/ $\text{CH}_3\text{CN}$	62

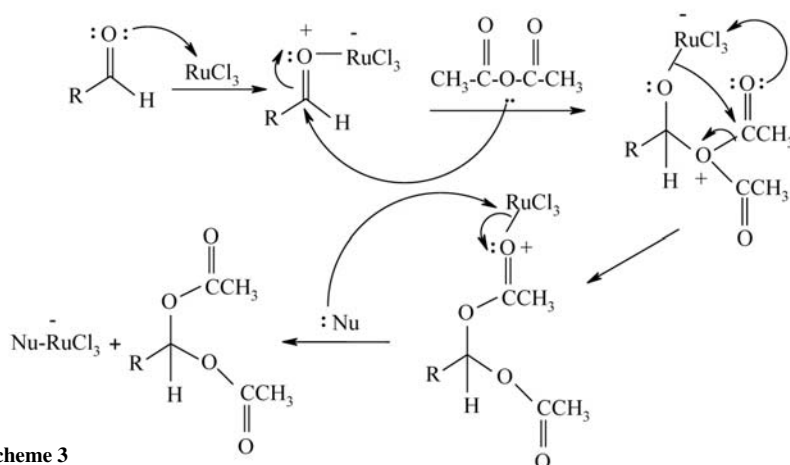


Scheme 2

**Table 2:** Chemoselective conversion of carbonyl compounds to corresponding acylals by ruthenium(III) chloride hydrate as catalyst under solvent free conditions.<sup>a,b</sup>

entry	substrate	mp (°C) or bp (°C) (mmHg)		time (min) / yield <sup>c</sup> (%)
		found	reported	
1	4-nitrobenzaldehyde	124–125	124–125 <sup>21</sup>	5/90
2	3-nitrobenzaldehyde	65–66	65–66 <sup>15</sup>	5/88
3	4-chlorobenzaldehyde	79–80	81–82 <sup>21</sup>	7/87
4	benzaldehyde	42–43	44–45 <sup>15</sup>	10 <sup>d</sup> /76 <sup>d</sup>
5	3-methoxybenzaldehyde <sup>e</sup>	Oil	Oil <sup>12</sup>	5/55
6	2,6-dichlorobenzaldehyde	88–89	88–89 <sup>21</sup>	5/87
7	4-cyanobenzaldehyde	97–98	98–100 <sup>21</sup>	7/71
8	vanillin <sup>f</sup>	90–91	90–91 <sup>12</sup>	5/63
9	furfural	49–50	52–53 <sup>15</sup>	5/70
10	4-nitroacetophenone	–	–	15(60) <sup>f</sup> /0(0) <sup>e</sup>
11	3-phenylpropionaldehyde	Oil	Oil <sup>21</sup>	6/72
12	isobutyraldehyde	185 (740)	183 (630) <sup>21</sup>	5/50
13	cyclohexanone	–	–	10(30) <sup>f</sup> /0(0) <sup>e</sup>
14	4-(dimethylamino)benzaldehyde	–	–	15(30) <sup>f</sup> /0(0) <sup>e</sup>
15	4-hydroxybenzaldehyde <sup>f</sup>	89–90	89–90 <sup>17</sup>	60 <sup>d</sup> /58

<sup>a)</sup> The ratio of substrate (mmol) / catalyst (g) / acetic anhydride (mmol) is 3 / 0.018 / 6 <sup>b)</sup> All products were known and characterized from their spectral data (IR, <sup>1</sup>H-NMR and MS) and comparison to authentic samples. <sup>c)</sup> Yields refer to isolated pure products. <sup>d)</sup> *n*-Hexane was used as solvent and reaction was carried out at r.t. <sup>e)</sup> The reaction was carried out under reflux condition in *n*-hexane as a solvent. <sup>f)</sup> The ratio of substrate (mmol) / catalyst (g) / acetic anhydride (mmol) is 3 / 0.036 / 9



Scheme 3

In our proposed mechanism,  $\text{RuCl}_3 \cdot x\text{H}_2\text{O}$  activates the carbonyl group of aldehydes very fast (Scheme 3). On the other hand, wet or supported  $\text{RuCl}_3$ , cannot catalyze acylal formation reaction.

## 4. Conclusion

We have established a mild and facile catalytic method for the synthesis of diacetates from aldehydes using ruthenium(III) chloride as an efficient heterogeneous inorganic catalyst at room temperature. Advantages of this method include high catalytic efficiency, the observed chemoselectivity, good to excellent yields, short reaction times and ease of operation and work-up.

## 5. Acknowledgement

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## Povzetek

Rutenijev(III) klorid katalizira pripravo 1,1-diacetатов iz aldehydov pod milimi pogoji ob prisotnosti topila ali pa tudi pod pogoji brez uporabe topil. Opisana metoda ima kar nekaj prednosti, kot npr. odlične izkoristke, enostavnost izvedbe in izolacije, zahteva kratke reakcijske čase, kaže visoko učinkovitost katalizatorja in tudi visoko kemoselektivnost.