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# Substituted tertiary phosphine Ru(II) organometallics: Catalytic utility on the hydrolysis of etofibrate in pharmaceuticals

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**Abstract**

Some new organometallics of ruthenium(II) of the type $[RuCl_2(COD)(CO)L]$ (**1a–f**) and $[RuCl_2(COD)L_2]$ (**2a–f**) (where L is substituted tertiary phosphines), have been synthesized by using precursors $[RuCl_2(COD)(CO)(CH_3CN)]$ (**1**) and $[RuCl_2(COD)(CH_3CN)_2]$ (**2**) with the substituted tertiary phosphine ligands in 1:1 and 1:2 molar ratio. The organometallics (**2a–f**) have been further reacted with carbonmonoxide to produce compounds of the type $[RuCl_2(CO)L_2]$ (**3a–f**). These compounds were characterized by elemental analysis, IR, NMR ($^1H$, $^{13}C$ and $^{31}P$), mass and electronic spectral data. The catalytic activity of all these organometallics were studied and found that they are efficient catalysts for hydrolysis of etofibrate. The hydrolyzed product was separated by column chromatography and the percent yields are found in the range of 98.6–99.1%.


*Keywords:* Synthesis; Ru(II) organometallics; Tertiary phosphines; Hydrolysis; Etofibrate

## 1. Introduction

The ruthenium(II) phosphine compounds are effective homogeneous catalysts for hydrolysis, hydrogenation and hydroformylation reactions [1–4]. In fact, the majority of catalytically useful ruthenium complexes are soluble only in organic solvents. In order to improve the solubility in polar solvents like water and ethanol, we have planned to introduce carboxylated groups on tertiary phosphines and synthesized their Ru(II) organometallics [5–9]. Hydrolysis of esters, peptides and proteins are important biological processes and very common in chemistry and biochemistry [10]. Metal catalyzed reactions for the hydrolysis [11–13] of esters have been extensively investigated. However, these methods require more time for the complete hydrolysis process. In our previous studies we have investigated the synthesis, characterization and catalytic hydrolysis of Ru(II) organometallics on rivastigmine tartrate and neostigmine bromide and they are found to be efficient in the hydrolysis [14]. As part of our investigation into designing new organometallics, we report here the synthesis, characterization and catalytic utility of Ru(II) organometallics containing (2-formyl phenyl)diphenylphosphine, (2-carboxyphenyl)diphenylphosphine, (3-carboxyphenyl) diphenylphosphine, (4-carboxyphenyl)diphenylphosphine, (carboxymethyl)-diphenyl phosphine and (2-pyridyl)diphenylphosphine as ligands. These organometallics were synthesized by using the precursors $[RuCl_2(COD)(CO)(CH_3CN)]$ (**1**) and $[RuCl_2(COD)(CH_3CN)_2]$ (**2**) and their structures were confirmed by elemental analysis, IR, NMR ($^1H$, $^{13}C$ and $^{31}P$), mass and electronic spectral data.

## 2. Experimental

### 2.1. Materials and instruments

Analar grade reagents and freshly distilled solvents were used throughout the investigations. All the substrates were purified before use. The starting materials viz. $[RuCl_2(COD)(CO)(CH_3CN)]$ (**1**), $[RuCl_2(COD)(CH_3CN)_2]$ (**2**) and substituted tertiary phosphines were prepared according to the literature procedure [15–19]. Reactions were carried out under nitrogen atmosphere using schlenk technique. The products were purified after separation and testified and their structural information was obtained by IR and NMR techniques. Micro analytical (C, N, H) data was obtained by using a PerkinElmer 240C CHN elemental analyzer. Molar conductance of the complexes was measured in dichloromethane using

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a systronic conductivity bridge of the type 305. UV–vis spectra were recorded on a Schimadzu MPS-5000 spectrophotometer. The IR spectra were recorded in KBr pellets on PerkinElmer-283 spectrophotometer. The scanning rate was 6 min in the range of 4000–200 $cm^{-1}$, $^{1}H$ NMR spectra on Bruker WH 270 (270 MHz) using $CDCl_3$/DMSO solvent, $^{13}C$ NMR on Bruker WH 270 (67.93 MHz), $^{31}P$ NMR on WH 270 (109.29 MHz). CEC-21-110B, Finningan Mat 1210 spectrometer operating at 70 eV using a direct inlet system for recording mass spectra.

### 2.2. Synthetic procedures

#### 2.2.1. $[RuCl_2(COD)(CO)(CH_3CN)]$ (1)

The precursor $[RuCl_2(COD)(CO)(CH_3CN)]$ was prepared [15] by reacting dimer $[RuCl_2(COD)]_2$ with CO and acetonitrile.

#### 2.2.2. Preparation of $[RuCl_2(COD)(CO)L]$ (1a–f)

To a stirred solution of substituted tertiary phosphine (L) (0.5 mmol) in 10 ml acetone $[RuCl_2(COD)(CO)(CH_3CN)]$ (0.5 mmol) in 10 ml of the same solvent was added over a period of 30 min. The mixture was refluxed under heat for 1 h after which the compound was obtained. The product was filtered by using a sintered glass filter, washed with diethyl ether and dried in vacuo. A similar synthetic procedure was applied to prepare complexes, **1b–f** in a quantitative yield.

#### 2.2.3. Preparation of $[RuCl_2(COD)(CH_3CN)_2]$ (2)

$[RuCl_2(COD)]_2$ (0.280 g, 0.5 mmol) was dissolved in acetonitrile (0.02 g, 0.5 mmol) and the mixture was heated under reflux for 0.5 h, after which the yellow colored precipitate was formed in the solution. The solution was filtered to get $[RuCl_2(CH_3CN)_2(COD)]$ [15] final precipitate after thorough wash with diethyl ether and dried in vacuo.

#### 2.2.4. Preparation of $[RuCl_2(COD)L_2]$ (2a–f)

To a stirred solution of substituted tertiary phosphine (L) (1 mmol) in 10 ml ethanol $[RuCl_2(COD)(CH_3CN)_2]$ (0.5 mmol) in 10 ml of the same solvent was added over a period of 30 min. The mixture was refluxed for 0.5 h to get a snuff colored precipitate in the solution. The compound obtained was filtered off, washed with diethyl ether and dried in vacuo. A similar synthetic procedure was applied to prepare complexes, **2b–f** in a quantitative yield.

#### 2.2.5. Preparation of $[RuCl_2(CO)_2L_2]$ (3a–f)

The solution of $[RuCl_2(COD)L_2]$ (0.5 mmol) dissolved in 10 ml of $CH_2Cl_2$ was taken in a schlenk flask through which CO gas was passed for 0.5 h, after which light cream colored compound was precipitated. The compound obtained was filtered off, washed with diethyl ether and dried in vacuo. A similar synthetic procedure was applied to prepare complexes, **3b–f** in a quantitative yield.

### 2.3. Hydrolysis of etofibrate

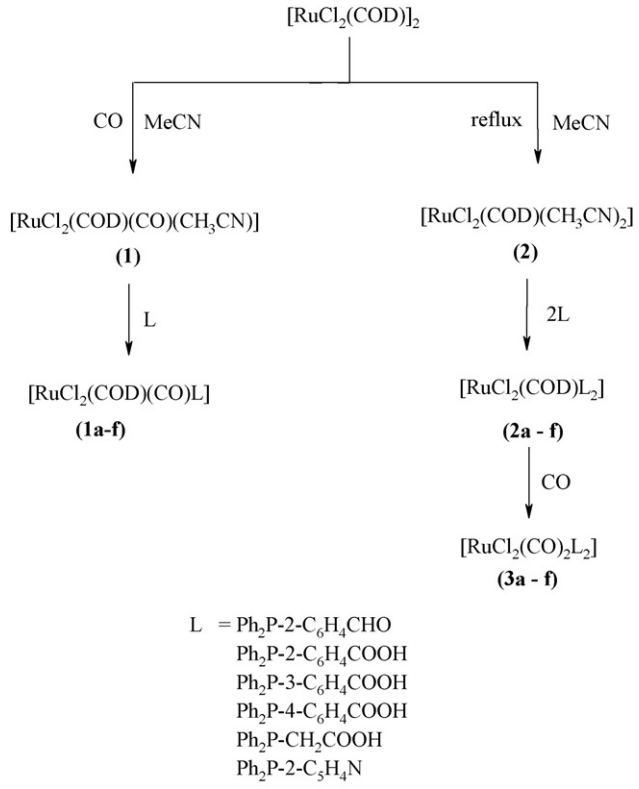
Hundred milligrams of etofibrate in 10 ml methanol was refluxed with 0.01 mol of ruthenium catalyst and 100 ml 0.1 M hydrochloric acid at 75 °C for 20 min. It was then evaporated and the residue was dried under vacuum. Two spots were observed on a TLC plate by using ethyl acetate:methanol (70:30, v/v) as mobile phase. The nicotinic acid formed in the process was collected by using a glass column (35 cm × 3 cm) packed with silica gel 60 (0.063–0.200 mm particle size) (E. Merck, Darmstadt, Germany) by using ethyl acetate:methanol (80:20, v/v) as mobile phase. The collected nicotinic acid was dissolved in water and a conductometric titration was carried out with 0.1N sodium hydroxide. The amount of nicotinic acid, which directly reflects the hydrolysis of EF, was calculated from the graph drawn between the volume of sodium hydroxide and corrected conductance.

## 3. Results and discussion

All the complexes are air stable, non hygroscopic. The physical and analytical data is in good agreement with the proposed molecular formulae (Table 1). A proposed synthetic route for ruthenium complexes is given in Scheme 1.

### 3.1. Infrared spectral data

A comparative study of the IR spectra of the precursors and their complexes confirmed the formation of the organometallics




Scheme 1. Synthetic routes of the 18 Ru(II) organometallics.

Table 1
Physical and analytical data of Ru(II) organometallics

| Compound no. | Ru(II) organometallics | Yield (g) (%) | Color | Analyses found (calculated %) | | |
|---|---|---|---|---|---|---|
| | | | | C | H | N |
| **1a** | $[RuCl_2(COD)(CO)(Ph_2P\text{-}2\text{-}C_6H_4CHO)]$ $C_{28}H_{27}O_2Cl_2PRu$ | 0.223 (70) | Gray | 56.82 (57.80) | 4.42 (4.64) | – |
| **1b** | $[RuCl_2(COD)(CO)(Ph_2P\text{-}2\text{-}C_6H_4COOH)]$ $C_{28}H_{27}O_3Cl_2PRu$ | 0.232 (72) | Light gray | 54.37 (54.73) | 4.23 (4.37) | – |
| **1c** | $[RuCl_2(COD)(CO)(Ph_2P\text{-}3\text{-}C_6H_4COOH)]$ $C_{28}H_{27}O_3Cl_2PRu$ | 0.228 (70) | Gray | 54.21 (54.73) | 4.13 (4.37) | – |
| **1d** | $[RuCl_2(COD)(CO)(Ph_2P\text{-}4\text{-}C_6H_4COOH)]$ $C_{28}H_{27}O_3Cl_2PRu$ | 0.235 (72) | Gray | 54.14 (54.73) | 4.13 (4.17) | – |
| **1e** | $[RuCl_2(COD)(CO)(Ph_2P\text{-}CH_2COOH)]$ $C_{23}H_{25}O_3Cl_2PRu$ | 0.213 (72) | Gray | 42.28 (42.33) | 3.78 (3.82) | – |
| **1f** | $[RuCl_2(COD)(CO)(Ph_2P\text{-}2\text{-}C_5H_4N)]$ $C_{26}H_{26}OCl_2$ NPRu | 0.310 (71) | Gray | 54.36 (54.64) | 4.35 (4.55) | 2.34 (2.45) |
| **2a** | $[RuCl_2(COD)(Ph_2P\text{-}2\text{-}C_6H_4CHO)_2]$ $C_{46}H_{42}O_2Cl_2P_2Ru$ | 0.330 (70) | Light snuff | 64.02 (64.11) | 4.06 (4.87) | |
| **2b** | $[RuCl_2(COD)(Ph_2P\text{-}2\text{-}C_6H_4COOH)_2]$ $C_{46}H_{42}O_4Cl_2P_2Ru$ | 0.346 (73) | Light gray | 61.73 (61.80) | 4.39 (4.71) | – |
| **2c** | $[RuCl_2(COD)(Ph_2P\text{-}3\text{-}C_6H_4COOH)_2]$ $C_{46}H_{42}O_4Cl_2P_2Ru$ | 0.270 (70) | Light snuff | 61.70 (61.80) | 4.62 (4.71) | – |
| **2d** | $[RuCl_2(COD)(Ph_2P\text{-}4\text{-}C_6H_4COOH)_2]$ $C_{46}H_{42}O_4Cl_2P_2Ru$ | 0.274 (72) | Light snuff | 61.50 (61.80) | 4.67 (4.71) | – |
| **2e** | $[RuCl_2(COD)(Ph_2P\text{-}CH_2COOH)_2]$ $C_{36}H_{38}O_4Cl_2P_2Ru$ | 0.302 (71) | Snuff | 56.07 (56.17) | 4.44 (4.94) | |
| **2f** | $[RuCl_2(COD)(Ph_2P\text{-}2\text{-}C_5H_4N)_2]$ $C_{42}H_{40}$ $N_2Cl_2P_2Ru$ | 0.280 (70) | Snuff | 61.89 (62.7 6) | 4.90 (4.98) | 2.97 (3.49) |
| **3a** | $[RuCl_2(CO)_2(Ph_2P\text{-}2\text{-}C_6H_4CHO)_2]$ $C_{40}H_{30}O_4Cl_2P_2Ru$ | 0.286 (72) | Light cream | 58.64 (59.33) | 3.64 (3.71) | – |
| **3b** | $[RuCl_2(CO)_2(Ph_2P\text{-}2\text{-}C_6H_4COOH)_2]$ $C_{40}H_{30}O_6Cl_2P_2Ru$ | 0.302 (72) | Cream | 56.92 (57.07) | 4.32 (4.37) | – |
| **3c** | $[RuCl_2(CO)_2(Ph_2P\text{-}3\text{-}C_6H_4COOH)_2]$ $C_{40}H_{30}O_6Cl_2P_2Ru$ | 0.298 (70) | Gray | 56.94 (57.07) | 3.43 (3.57) | – |
| **3d** | $[RuCl_2(CO)_2(Ph_2P\text{-}4\text{-}C_6H_4COOH)_2]$ $C_{40}H_{30}O_6Cl_2P_2Ru$ | 0.294 (70) | Light cream | 56.03 (57.07) | 3.07 (3.57) | – |
| **3e** | $[RuCl_2(CO)_2(Ph_2P\text{-}CH_2COOH)_2]$ $C_{30}H_{26}O_6Cl_2P_2Ru$ | 0.240 (72) | White | 50.01 (50.27) | 3.02 (3.61) | – |
| **3f** | $[RuCl_2(CO)_2(Ph_2P\text{-}2\text{-}C_5H_4N)_2]$ $C_{36}H_{28}O_2N_2Cl_2P_2Ru$ | 0.250 (69) | Cream | 59.26 (59.62) | 3.73 (3.86) | 3.68 (3.86) |

with the proposed coordination pattern. The characteristic sharp and medium absorption band is observed at 2200 $cm^{-1}$, corresponding to acetonitrile, which disappeared in the complexes **1a–f** and **2a–f** revealing that this group is replaced by tertiary phosphine ligand [20]. The IR spectra of the complexes **1a–f** and **2a–f** formed with different tertiary phosphines show a strong absorption band in the range of 1580–1595 $cm^{-1}$ which is attributed to the involvement of cyclooctadiene moiety in coordination with metal center [21]. The complexes **1a–f** exhibited strong absorption band around 1980–2000 $cm^{-1}$ which is assigned to $\nu$(Ru–CO). Further, the complexes **3a–f** have shown two characteristic bands around 2070 and 2000 $cm^{-1}$ and assigned to the arrangement of two CO molecules in *cis*-configuration around the metal center [22]. A strong band is observed in the complexes **1b–e**, **2b–e** and **3b–e** in the range of 1705–1720 $cm^{-1}$, which corresponds to $\nu$(COOH) of tertiary phosphine and is attributed to the non-involvement of carboxylic functional group of tertiary phosphine ligands with the metal center [16,17]. The absorption band shown by the complexes **1a**, **2a** and **3a** around 1670–1690 $cm^{-1}$ is attributed to uncoordinated formyl group of tertiary phosphine ligands to metal center [8]. Far IR spectra of all the complexes exhibit only one strong absorption band in the range of 504–530 $cm^{-1}$ which is assigned to $\nu$(Ru–P) [23]. The two absorption bands are observed for all complexes around 305–310 and 325–350 $cm^{-1}$ and assigned to the arrangement of two chlorides in *cis*-configuration around the metal center [24]. The IR spectrum of [$RuCl_2$ (COD) (CO) ($Ph_2$-P-3-$C_6H_4$COOH)] is presented in Fig. 1.

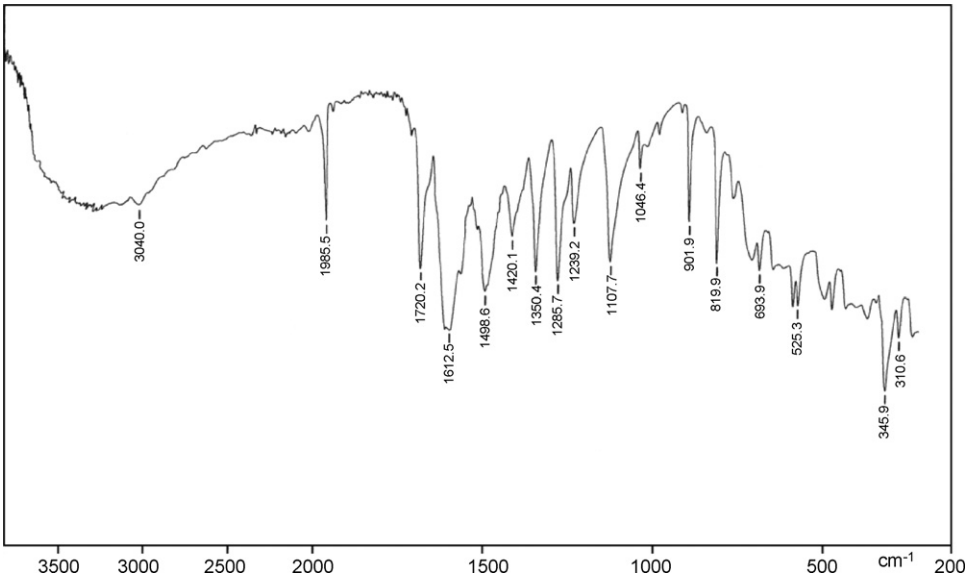



Fig. 1. IR spectrum of [$RuCl_2$(COD)(CO)($Ph_2$-P-3-$C_6H_4$COOH)].

Table 2
$^1$H NMR spectral data of Ru(II) organometallics

| Compound no. | Ru(II) organometallics | $^1$H peak positions (ppm) | | | | |
|---|---|---|---|---|---|---|
| | | Cyclooctadiene (COD) | | | Tertiary phosphines | |
| | | $CH_2$(m) | $CH_2$(m) | =CH(m) | Aryl(m) | COOH(br) |
| **1a** | [$RuCl_2$(COD)(CO)($Ph_2$P-2-$C_6H_4$CHO)] | 1.53 | 2.41 | 4.04 | 6.80–8.08 | 10.56* |
| **1b** | [$RuCl_2$(COD)(CO)($Ph_2$P-2-$C_6H_4$COOH)] | 1.71 | 2.39 | 4.11 | 6.70–8.20 | 12.11 |
| **1c** | [$RuCl_2$(COD)(CO)($Ph_2$P-3-$C_6H_4$COOH)] | 1.68 | 2.32 | 4.03 | 6.82–8.20 | 11.06 |
| **1d** | [$RuCl_2$(COD)(CO)($Ph_2$P-4-$C_6H_4$COOH)] | 1.64 | 2.39 | 4.06 | 6.81–8.40 | 11.80 |
| **1e** | [$RuCl_2$(COD)(CO)($Ph_2$P-$CH_2$COOH)] | 1.71 | 2.38 | 4.05 | 6.90–8.10<br>3.50(d)** | 11.87 |
| **1f** | [$RuCl_2$(COD)(CO)($Ph_2$P-2-$C_5H_4$N)] | 1.60 | 2.40 | 4.12 | 7.10–8.30 | – |
| **2a** | [$RuCl_2$(COD)($Ph_2$P-2-$C_6H_4$CHO)$_2$] | 1.50 | 2.41 | 4.11 | 6.50–8.00 | 10.60* |
| **2b** | [$RuCl_2$(COD)($Ph_2$P-2-$C_6H_4$COOH) $_2$] | 1.68 | 2.32 | 4.01 | 6.30–8.20 | 12.30 |
| **2c** | [$RuCl_2$(COD)($Ph_2$P-3-$C_6H_4$COOH)$_2$] | 1.71 | 2.41 | 4.03 | 6.98–8.00 | 12.20 |
| **2d** | [$RuCl_2$(COD)($Ph_2$P-4-$C_6H_4$COOH)$_2$] | 1.52 | 2.33 | 4.04 | 6.82–8.30 | 12.38 |
| **2e** | [$RuCl_2$(COD)($Ph_2$P-$CH_2$COOH)$_2$] | 1.64 | 2.39 | 4.12 | 6.41–8.40<br>3.56(d)** | 12.31 |
| **2f** | [$RuCl_2$(COD)($Ph_2$P-2-$C_5H_4$N)$_2$] | 1.72 | 2.38 | 4.05 | 7.10–8.20 | – |
| **3a** | [$RuCl_2$(CO)$_2$($Ph_2$P-2-$C_6H_4$CHO)$_2$] | – | – | – | 6.34–7.90 | 10.56* |
| **3b** | [$RuCl_2$(CO)$_2$($Ph_2$P-2-$C_6H_4$COOH) $_2$] | – | – | – | 6.31–8.30 | 12.04 |
| **3c** | [$RuCl_2$(CO)$_2$($Ph_2$P-3-$C_6H_4$COOH)$_2$] | – | – | – | 6.80–8.20 | 12.05 |
| **3d** | [$RuCl_2$(CO)$_2$($Ph_2$P-4-$C_6H_4$COOH)$_2$] | – | – | – | 6.34–8.30 | 11.50 |
| **3e** | [$RuCl_2$(CO)$_2$($Ph_2$P-$CH_2$COOH)$_2$] | – | – | – | 6.50–8.30<br>3.56(d)** | 12.25 |
| **3f** | [$RuCl_2$(CO)$_2$($Ph_2$P-2-$C_5H_4$N)$_2$] | – | – | – | 6.40–8.20 | – |

* CHO.
** $CH_2$–COOH.

### 3.2. $^1$H NMR spectral data

The $^1$H NMR spectra of the precursor as well as its corresponding metal complexes have been recorded in DMSO-$d_6$ using TMS as internal standard. The $^1$H NMR spectral data of all the Ru(II) organometallics is listed in Table 2. The sharp singlet signal observed in the range of 11.06–12.38 ppm in complexes **1b–e**, **2b–e** and **3b–e** is attributed to uncoordinated carboxylic group of tertiary phosphine with metal center [16]. The absorption band exhibited by the spectra of complexes **1a**, **2a** and **3a** around 10.56 ppm is ascribed to non-involvement of formyl group of tertiary phosphine in coordination [8]. The aromatic protons of various environments present in all complexes appeared as multiplets in the range of 6.30–8.40 ppm [25]. The doublet signal exhibited by complexes **1e**, **2e** and **3e** in the range of 3.50–3.56 ppm is assigned to –$CH_2$ proton of (carboxymethyl)diphenylphosphine ligand [16]. The $^1$H NMR spectra of complexes **1a–f** and **2a–f** gave multiplet signals around 1.50–1.72 and 2.32–2.41 ppm which are assigned to two different –$CH_2$ groups that are present in the cyclooctadiene. Another multiplet exhibited by the above complexes in the range of 4.04–4.12 ppm is attributed to =CH– group of cyclooctadiene coordinated to metal center [21]. The $^1$H NMR spectrum of [$RuCl_2$ (COD) (CO) ($Ph_2$-P-3-$C_6H_4$COOH)] is presented in Fig. 2.

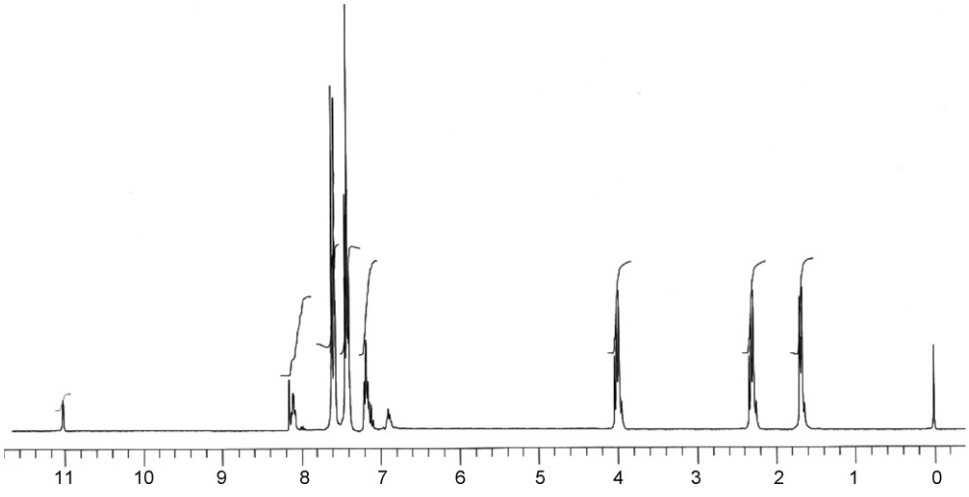



Fig. 2. $^1$H NMR spectrum of [$RuCl_2$(COD)(CO)($Ph_2$-P-3-$C_6H_4$COOH)].

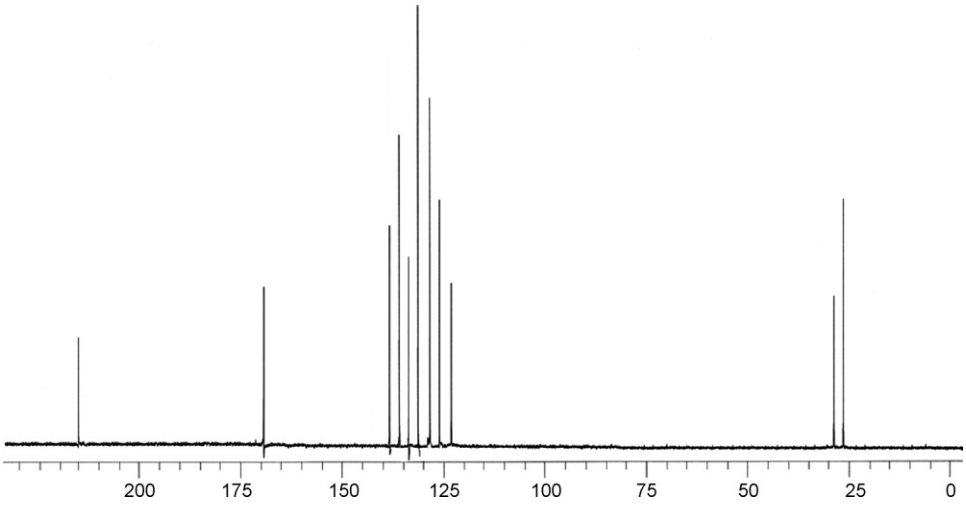



Fig. 3. $^{13}$C NMR spectrum of [$RuCl_2$(COD)(CO)($Ph_2$-P-3-$C_6H_4$COOH)].

### 3.3. $^{13}$C NMR spectral data

$^{13}$C NMR signals are assigned for the complexes by the comparison with the spectra of the corresponding tertiary phosphine ligands. The coordinated cyclooctadiene (COD) exhibits three different signals around 28.45, 26.75 and 123.50 ppm which are assigned to $–CH_2$ (A), $–CH_2$ (B) and =CH– groups of cyclooctadiene in the complexes **1a–f** and **2a–f** [21]. The aromatic carbons of various environments present in all the organometallics appeared as signals in the range of 126.00–138.00 ppm. The doublet signal is observed for the complexes **1e**, **2e** and **3e** around 40.75–43.78 ppm and assigned to methylene carbon of (carboxymethyl)diphenylphosphine ligand [16]. The sharp signal shown by the complexes **1a**, **2a** and **3a** in the range of 180.00–183.00 ppm is assigned to formyl carbon of the tertiary phosphine ligand [8]. The absorption band shown by the complexes **1b–e**, **2b–e** and **3b–e** in the range of 167.00–175.80 ppm is ascribed to non-involvement of carboxylic group of tertiary phosphine in coordination with metal center [16,17]. The presence of carbonyl carbon signal in the range of 201.16–218.80 ppm for the complexes **1a–f** and **3a–f** suggests its coordination with ruthenium metal [26,27]. The $^{13}$C

Table 3
$^{13}$C & $^{31}$P NMR spectral data of Ru(II) organometallics

| Compound no. | Ru(II) organometallics | $^{13}$C peak positions (ppm) | | | | | | $^{31}$P NMR (ppm) |
|---|---|---|---|---|---|---|---|---|
| | | Cyclooctadiene (COD) | | | | Tertiary phosphines | | |
| | | CO | $–CH_2$ | $–CH_2$ | =CH– | Aryl(m) | COOH(br) | |
| **1a** | [$RuCl_2$(COD)(CO)($Ph_2$P-2-$C_6H_4$CHO)] | 207.20 | 28.52 | 26.75 | 124.50 | 126–132 | 183.00* | 30.24 |
| **1b** | [$RuCl_2$(COD)(CO)($Ph_2$P-2-$_6H_4$COOH)] | 209.50 | 26.34 | 27.53 | 122.15 | 132–137 | 167.00 | 31.32 |
| **1c** | [$RuCl_2$(COD)(CO)($Ph_2$P-3-$C_6H_4$COOH)] | 215.10 | 27.35 | 28.00 | 123.45 | 126–138 | 168.25 | 32.63 |
| **1d** | [$RuCl_2$(COD)(CO)($Ph_2$P-4-$C_6H_4$COOH)] | 217.12 | 28.32 | 28.32 | 122.15 | 128–130 | 169.40 | 32.52 |
| **1e** | [$RuCl_2$(COD)(CO)($Ph_2$P-$CH_2$COOH)] | 218.70 | 27.45 | 29.35 | 121.45 | 128–132 | 167.36<br>40.75** | 31.34 |
| **1f** | [$RuCl_2$(COD)(CO)($Ph_2$P-2-$C_5H_4$N)] | 215.00 | 29.42 | 27.43 | 125.35 | 126–133 | – | 32.35 |
| **2a** | [$RuCl_2$(COD)($Ph_2$P-2-$C_6H_4$CHO)$_2$] | – | 28.50 | 28.30 | 124.15 | 126–132 | 180.00* | 31.92 |
| **2b** | [$RuCl_2$(COD)($Ph_2$P-2-$C_6H_4$COOH) $_2$] | – | 28.30 | 27.53 | 122.15 | 125–134 | 172.00 | 30.82 |
| **2c** | [$RuCl_2$(COD)($Ph_2$P-3-$C_6H_4$COOH)$_2$] | – | 28.43 | 28.12 | 123.34 | 128–136 | 170.80 | 30.72 |
| **2d** | [$RuCl_2$(COD)($Ph_2$P-4-$C_6H_4$COOH)$_2$] | – | 28.12 | 28.13 | 123.45 | 128–137 | 174.00 | 32.05 |
| **2e** | [$RuCl_2$(COD)($Ph_2$P-$CH_2$COOH)$_2$] | – | 28.34 | 28.14 | 120.43 | 125–138 | 175.80<br>43.78** | 31.43 |
| **2f** | [$RuCl_2$(COD)($Ph_2$P-2-$C_5H_4$N)$_2$] | – | 29.24 | 28.20 | 121.45 | 126–133 | – | 32.15 |
| **3a** | [$RuCl_2$(CO)$_2$($Ph_2$P-2-$C_6H_4$CHO)$_2$] | 201.16 | – | – | – | 125–130 | 182.50* | 30.24 |
| **3b** | [$RuCl_2$(CO)$_2$($Ph_2$P-2-$C_6H_4$COOH) $_2$] | 205.12 | – | – | – | 130–137 | 173.20 | 31.75 |
| **3c** | [$RuCl_2$(CO)$_2$($Ph_2$P-3-$C_6H_4$COOH)$_2$] | 206.10 | – | – | – | 126–138 | 173.20 | 34.69 |
| **3d** | [$RuCl_2$(CO)$_2$($Ph_2$P-4-$C_6H_4$COOH)$_2$] | 217.14 | – | – | – | 130–136 | 174.31 | 30.75 |
| **3e** | [$RuCl_2$(CO)$_2$($Ph_2$P-$CH_2$COOH)$_2$] | 218.40 | – | – | – | 128–133 | 173.42<br>41.75** | 32.40 |
| **3f** | [$RuCl_2$(CO)$_2$($Ph_2$P-2-$C_5H_4$N)$_2$] | 215.10 | – | – | – | 132–138 | – | 32.05 |

* CHO.
** $CH_2$–COOH.

NMR spectrum of [$RuCl_2$(COD)(CO)($Ph_2$-P-3-$C_6H_4$COOH)] is presented in Fig. 3.

### 3.4. $^{31}$P NMR spectral data

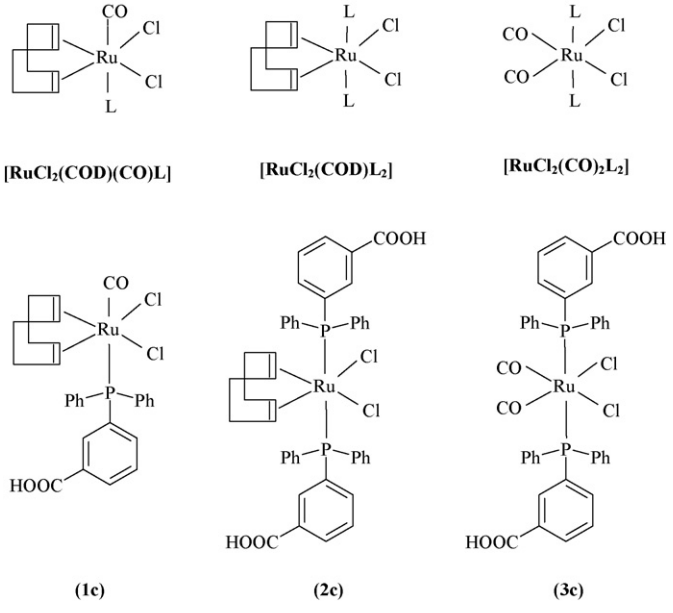
$^{31}$P NMR spectral data of complexes **1a–f** exhibit only one singlet signal in the down field region in the range of 30.24–34.70 ppm which can strongly support the coordination of phosphorous atoms of tertiary phosphines to the Ru(II) [28,29]. Further, the appearance of a singlet peak in the complexes **2a–f** and **3a–f** reveals that the two phosphine ligands are arranged in the trans position around the metal center [3]. The $^{13}$C and $^{31}$P NMR spectral data is presented in Table 3.

### 3.5. Mass spectral data

The proposed molecular formulae of a ruthenium(II) organometallics were confirmed by the mass spectral analysis by comparing their molecular weights with *m*/*z* values. The mass spectra contain molecular ion peaks at *m*/*z* ($M^+$) 598.0 for 1a, 614.5 for 1b, 614.2 for 1c, 614.0 for 1d, 552.2 for 1e, 571.4 for 1f, 860.2 for 2a, 892.0 for 2b, 892.1 for 2c, 892.0 for 2d, 768.4 for 2e, 806.2 for 2f, 808.5 for 3a, 840.0 for 3b, 840.4 for 3c, 840.1 for 3d, 716.5 for 3e and 754.2 for 3f. This data is in good agreement with the respective molecular formulae.

### 3.6. Electronic spectral data

UV–vis spectra of all the ruthenium(II) complexes exhibit two d–d bands, of which one is a weak band at 650–586 nm that corresponds to the transition $^1A_{1g} \rightarrow {}^1T_{1g}$ and another strong absorption band at 425–403 nm is assigned to $^1A_{1g} \rightarrow {}^1T_{2g}$ transition. On the other hand, the two high-energy intensity bands are also found in the region of 351–300 and 291–245 nm, which may be considered as charge transfer transitions [3].




Scheme 2. Representative structures of Ru(II) organometallics.

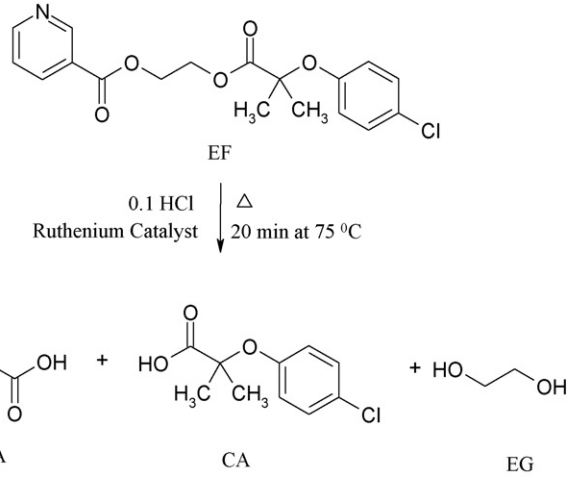
On the basis of analytical and spectral data, octahedral structures (Scheme 2) have been tentatively proposed for all the Ru(II) organometallics

## 4. Catalytic applications

Etofibrate (2-(*p*-chlorophenoxy)-2-methylpropionicacid-2-(nicotinoyl-oxy)ethyl ester, EF), a derivative of nicotinic acid and clofibrate is a lipid regulating drug used in the treatment of hyperlipidaemias [30]. Recently, the hydrolysis of EF by hydrochloric acid leading to the formation of 3-pyridinecarboxylic acid (nicotinic acid, NA), 2-(*p*-chlorophenoxy)-2-methylpropionic acid (clofibricacid, CA) and 1,2-ethane diol (ethylene glycol, EG) was reported. The formation of NA, CA and EG was also confirmed by IR and PMR analysis. However, it was reported that the hydrolysis process was initiated only after 3 h and completed after 12 h [31]. Since, there is a need for the development of faster hydrolysis method,

Table 4
Percent yields of NA formed after EF using ruthenium catalysts

| Compound no. | Ru(II) organometallics | Yield (%) |
|---|---|---|
| **1a** | [$RuCl_2$(COD)(CO)($Ph_2$P-2-$C_6H_4$CHO)] | 98.8 |
| **1b** | [$RuCl_2$(COD)(CO)($Ph_2$P-2-$_6H_4$COOH)] | 98.6 |
| **1c** | [$RuCl_2$(COD)(CO)($Ph_2$P-3-$C_6H_4$COOH)] | 99.1 |
| **1d** | [$RuCl_2$(COD)(CO)($Ph_2$P-4-$C_6H_4$COOH)] | 98.6 |
| **1e** | [$RuCl_2$(COD)(CO)($Ph_2$P-$CH_2$COOH)] | 98.8 |
| **1f** | [$RuCl_2$(COD)(CO)($Ph_2$P-2-$C_5H_4$N)] | 98.9 |
| **2a** | [$RuCl_2$(COD)($Ph_2$P-2-$C_6H_4$CHO)$_2$] | 98.9 |
| **2b** | [$RuCl_2$(COD)($Ph_2$P-2-$C_6H_4$COOH) $_2$] | 98.7 |
| **2c** | [$RuCl_2$(COD)($Ph_2$P-3-$C_6H_4$COOH)$_2$] | 99.1 |
| **2d** | [$RuCl_2$(COD)($Ph_2$P-4-$C_6H_4$COOH)$_2$] | 99.0 |
| **2e** | [$RuCl_2$(COD)($Ph_2$P-$CH_2$COOH)$_2$] | 98.8 |
| **2f** | [$RuCl_2$(COD)($Ph_2$P-2-$C_5H_4$N)$_2$] | 99.0 |
| **3a** | [$RuCl_2$(CO)$_2$($Ph_2$P-2-$C_6H_4$CHO)$_2$] | 98.6 |
| **3b** | [$RuCl_2$(CO)$_2$($Ph_2$P-2-$C_6H_4$COOH) $_2$] | 98.6 |
| **3c** | [$RuCl_2$(CO)$_2$($Ph_2$P-3-$C_6H_4$COOH)$_2$] | 99.1 |
| **3d** | [$RuCl_2$(CO)$_2$($Ph_2$P-4-$C_6H_4$COOH)$_2$] | 98.8 |
| **3e** | [$RuCl_2$(CO)$_2$($Ph_2$P-$CH_2$COOH)$_2$] | 98.9 |
| **3f** | [$RuCl_2$(CO)$_2$($Ph_2$P-2-$C_5H_4$N)$_2$] | 98.6 |




Scheme 3. Hydrolysis of EF in the presence of ruthenium catalysts.

the newly synthesized ruthenium organometallics were used as catalysts in the present investigations. The hydrolysis time was monitored by determining the produced amount of nicotinic acid (Scheme 3) with conductometric titration using 0.1N sodium hydroxide. It was observed that the present catalysts are able to successfully hydrolyze EF within 20 min. The percent yields of NA were found to be in the range of 98.6–99.1% (Table 4).

## 5. Conclusions

Based on the infrared, $^{1}H$, $^{13}C$ NMR and mass spectral data it is found that, the Ru(II) metal center is occupied by COD, chloride ions, tertiary phosphines and carbonmonoxide groups. In all the organometallics, the two chloride atoms are arranged in *cis* position whereas in **2a–f** and **3a–f** organometallics the two phosphine ligands are present in the *trans* position around the metal centre as evidenced by $^{31}P$ NMR. The structures are proposed tentatively as octahedral for all the above Ru(II) organometallics. These organometallics are found to be efficient catalysts in the hydrolysis of etofibrate. This method is simple to set-up, requires short reaction times and produces high product yields.

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