Supplementary Material (ESI) for Chemical Communications

VO(salen)(X) catalysed asymmetric cyanohydrin synthesis: an unexpected influence of the nature of anion X on the catalytic activity

Supplementary information

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Synthesis and characterization of complexes 2-6

Synthesis of vanadium(V)(salen) tetrafluoroborate 3

A column packed with DOWEX® 1X8-400 resin (10 mL) was firstly converted into the hydroxide form of the resin by washing with concentrated NaOH solution. An aqueous solution containing a three fold excess of sodium tetrafluoroborate was then used to convert the resin into the tetrafluoroborate salt.

Ethyl sulfonate complex **2** (380 mg, 0.51 mmol) was dissolved in MeOH (50 mL) and water (25 mL). The solution was passed twice through the ion exchange column. The eluted solution was evaporated *in vacuo* and the residue was purified by column chromatography on silica gel eluting first with CH_2Cl_2, then with a 2:1 mixture of ethyl acetate and hexane to give complex **3** (329 mg, 93%) as a dark green powder. $[\alpha]_D^{20}$ -1860 (c 0.005, $CHCl_3$); δ_H (300Mz, $CDCl_3$) 1.30 (9H, s, $C(CH_3)_3$), 1.32 (9H, s, $C(CH_3)_3$), 1.35 (9H, s, $C(CH_3)_3$), 1.43 (9H, s, $C(CH_3)_3$), 1.5-1.7 (1H, m, CH_2), 1.9-2.1 (3H, m, CH_2CH_2), 2.3-2.4 (3H, m, CH_2CH_2), 2.6-2.7 (1H, m, CH_2), 3.7-3.8 (1H, m, NCH), 3.8-3.9 (1H, m, NCH), 7.5-7.6 (2H, m, ArCH), 7.67 (1H, s, ArCH), 7.73 (1H, s, ArCH), 8.60 (1H, s, CH=N), 8.76 (1H, s, CH=N); δ_F (470Mz, $CDCl_3$, externally referenced to $CFCl_3$) -151.83 (1F, t $^1J_{BF}$ 6.1Hz, V-F-B), -151.88 (3F, t $^1J_{BF}$ 5.4Hz, BF_3); δ_C (125Mz, $CDCl_3$) 23.7, 24.4, 28.6, 29.2, 29.6, 29.8, 30.8, 31.2, 31.3, 34.6, 35.5, 35.7, 70.4, 71.3, 120.9, 121.3, 128.6, 130.2, 131.1, 132.6, 135.0, 135.7, 144.9, 145.1, 160.4, 162.0, 162.6, 164.4; Found: C, 60.77; H, 7.71; N, 3.76%; $C_{36}H_{52}N_2O_3VBF_4.H_2O$ requires: C, 60.34; H, 7.54; N, 3.91%; Found (ES^+) 611.3413. $C_{36}H_{52}N_2O_3V$ (M^+-BF_4) requires 611.3412.

Synthesis of vanadium(V)(salen) chloride 4

Salen ligand (344 mg, 0.63 mmol) was dissolved in THF (20 mL), and $VOCl_3$ (0.09 mL, 0.96 mmol) was added with stirring. The solution was stirred at room temperature for 30 minutes, then the solvent was evaporated and the product was purified by silica gel chromatography using

first a 3:1 EtOAc-hexane mixture, then a 1:1:1 EtOAc-hexane-MeOH mixture as eluent. The dark green fractions were collected and evaporated *in vacuo*, to give compound **4** (244 mg, 60%) as a green powder. $[\alpha]_D^{20}$ -1340 (c 0.01, $CHCl_3$); δ_H (300Mz, $CDCl_3$) 1.35 (9H, s, $C(CH_3)_3$), 1.37 (9H, s, $C(CH_3)_3$), 1.53 (9H, s, $C(CH_3)_3$), 1.55 (9H, s, $C(CH_3)_3$), 1.5-1.6 (1H, m, CH_2), 1.9-2.1 (3H, m, CH_2CH_2), 2.4-2.5 (1H, m, CH_2), 2.5-2.8 (3H, m, CH_2CH_2), 3.7-3.8 (1H, m, NCH), 4.3-4.4 (1H, m, NCH), 7.45 (1H, s, ArCH), 7.54 (1H, s, ArCH), 7.70 (1H, s, ArCH), 7.74 (1H, s, ArCH), 8.48 (1H, s, CH=N), 8.67 (1H, s, CH=N); δ_C (125Mz, $CDCl_3$) 23.9, 24.4, 28.3, 29.1, 29.3, 29.8, 30.8, 31.8, 32.8, 34.4, 35.4, 35.7, 70.0, 71.2, 120.8, 121.7, 128.8, 130.2, 131.4, 132.6, 134.9, 135.6, 143.9, 144.0, 160.8, 161.1, 162.1, 164.7; Found: C, 64.25; H, 8.59; N, 3.80; Cl, 4.53% $C_{36}H_{52}N_2O_3Cl.H_2O.EtOH$ requires: C, 64.17; H, 8.50; N, 3.94; Cl, 4.53%; Found (ES^+) 611.3412. $C_{36}H_{52}N_2O_3V$ (M^+-Cl) requires 611.3412.

Synthesis of vanadium(V)(salen) bromide 5

A column packed with DOWEX® 1X8-400 resin (10 mL) was firstly converted into the hydroxide form of the resin by washing with concentrated NaOH solution. An aqueous solution containing a three fold excess of sodium bromide was then used to convert the resin into the bromide salt.

Tetrafluoroborate complex **3** (329 mg, 0.47 mmol) was dissolved in methanol (50 mL) and water (25 mL). The solution was passed twice through the ion exchange column. The eluted solution was evaporated *in vacuo* and the residue was purified by column chromatography on silica gel eluting first with CH_2Cl_2, then with methanol to give complex **5** (285 mg, 87%) as a dark green powder. $[\alpha]_D^{20}$ -1120 (c 0.005, $CHCl_3$); δ_H (500Mz, $CDCl_3$) 1.42 (18H, s, 2x$C(CH_3)_3$), 1.55 (18H, s, 2x$C(CH_3)_3$), 1.2-1.8 (3H, m, CH_2CH_2), 2.0-2.2 (2H, m, CH_2), 2.3-2.5 (2H, m, CH_2), 2.8-2.9 (1H, m, CH_2), 3.9-4.0 (1H, m, NCH), 4.7-4.8 (1H, m, NCH), 7.64 (1H, s, ArCH), 7.69 (1H, s, ArCH), 7.78 (1H, s, ArCH), 7.83 (1H, s, ArCH), 8.77 (1H, s, CH=N), 8.83 (1H, s, CH=N); δ_C (125Mz, $CDCl_3$) 23.7, 24.5, 28.5, 29.6, 29.8, 30.8, 31.2, 31.3, 34.4, 35.4, 35.6, 69.4, 71.2, 120.9, 121.7, 128.4, 130.2,

131.7, 132.1, 134.9, 135.4, 144.4, 144.6, 160.5, 160.9, 162.5, 164.3; Found: C, 58.58; H, 7.33; N, 3.53%; $C_{36}H_{52}N_2O_3Br.2.5H_2O$ requires: C, 58.69; H, 7.74; N, 3.80%; Found (ES^+) 611.3408. $C_{36}H_{52}N_2O_3V$ (M^+-Br) requires 611.3412. The negative ion spectrum also shows a peak at 627 consistent with (MOH^--Br).

Synthesis of vanadium(V)(salen) triflate 6

A column packed with DOWEX® 1X8-400 resin (10 mL) was firstly converted into the hydroxide form of the resin by washing with concentrated NaOH solution. An aqueous solution containing a three fold excess of sodium triflate was then used to convert the resin into the triflate salt.

Tetrafluoroborate complex **3** (320 mg, 0.46 mmol) was dissolved in methanol (75 mL) and water (50 mL). The solution was passed twice through the ion exchange column. The eluted solution was evaporated *in vacuo* and the residue was purified by column chromatography on silica gel eluting first with CH_2Cl_2, then with a 1:1 mixture of ethyl acetate and hexane to give complex **6** (245 mg, 68%) as a dark green powder. $[\alpha]_D^{20}$ -1049 (c 0.005, $CHCl_3$); δ_H (300Mz, $CDCl_3$) 1.29 (9H, s, $C(CH_3)_3$), 1.32 (9H, s, $C(CH_3)_3$), 1.44 (18H, s, 2x$C(CH_3)_3$), 1.5-2.2 (4H, m, CH_2CH_2), 2.4-2.5 (3H, m, CH_2CH_2), 2.7-2.8 (1H, m, CH_2CH_2), 3.7-3.8 (1H, m, NCH), 3.9-4.0 (1H, m, NCH), 7.48 (1H, s, ArCH), 7.52 (1H, s, ArCH), 7.66 (1H, s, ArCH), 7.72 (1H, s, ArCH), 8.52 (1H, s, CH=N), 8.72 (1H, s, CH=N); δ_F (470Mz, $CDCl_3$, externally referenced to $CFCl_3$) -79.24; δ_C (125Mz, $CDCl_3$) 23.9, 24.4, 29.0, 29.2, 29.6, 29.9, 30.7, 31.2, 31.3, 34.5, 35.5, 35.7, 70.2, 71.0, 119.7 (q *J* 319 Hz, CF_3), 120.8, 121.5, 128.4, 129.6, 132.0, 132.4, 135.1, 135.7, 144.5, 144.7, 160.8, 161.6, 162.0, 164.6; Found: C, 58.55; H, 6.82; N, 3.51%; $C_{37}H_{52}F_3N_2O_6SV$ requires: C, 58.42, H, 6.84, N, 3.68%; Found (ES^+) 611.3416. $C_{36}H_{52}N_2O_3V$ (M^+-OTf) requires 611.3412. The negative ion spectrum also shows a peak at 628 consistent with (MOH^--OTf).

Kinetics experiments

General procedure for reaction kinetics

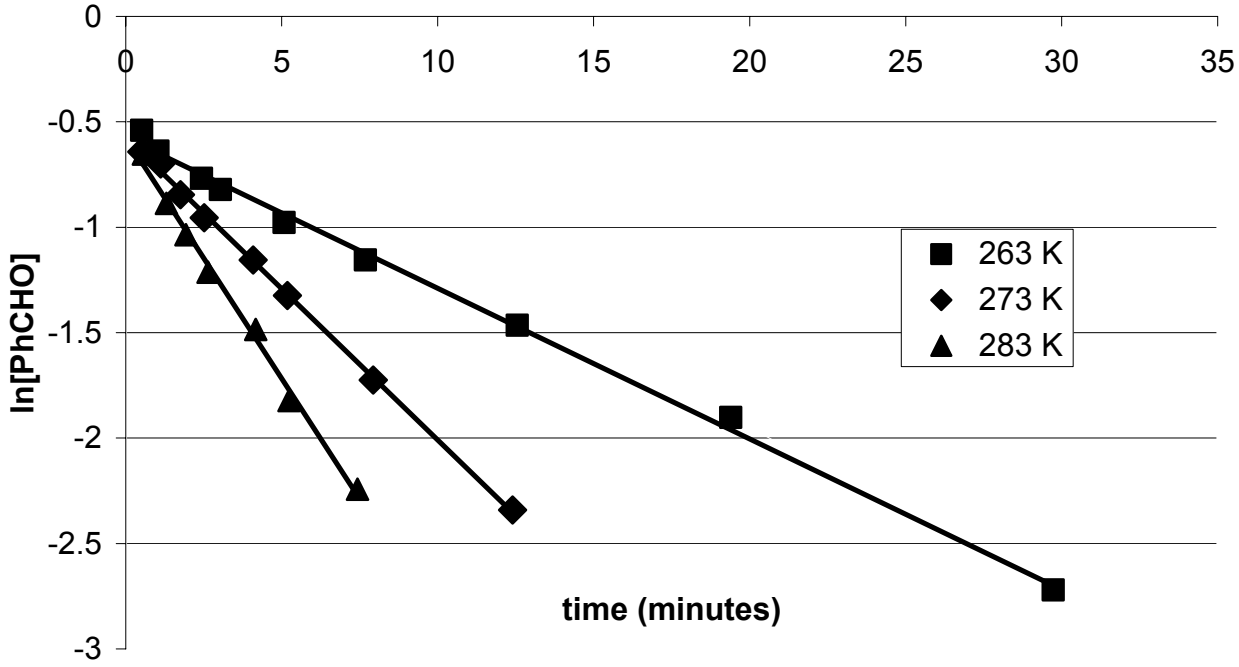
To a dry sealed round-bottomed flask fitted with a stirrer was added a solution of catalyst **1-6** (0.00196 mmol, 0.2 mol% for complexes **2-6;** 0.00098 mmol (0.2 mol% of titanium ions) for complex **1**) in dry CH_2Cl_2 (1.75 mL). The solution adjusted to the appropriate temperature and an aliquot (0.7 μL) was taken and diluted with dry CH_2Cl_2 (3.0 mL). The absorbance of the diluted sample was measured at 240-260 nm, this reading being used for baseline calibration. Freshly distilled benzaldehyde (0.1 mL, 1.0 mmol) was added to the reaction which was stirred for 10 minutes and the first aliquot (t = 0) was taken as described above. Then, trimethylsilyl cyanide (0.15 mL, 1.1 mmol) was added and aliquots were taken at approximate intervals of 0.5, 1, 2, 3, 5, 7.5, 10, 15, 20, 25, and 30 minutes, and then every ten minutes as necessary.

For kinetics experiments using in situ prepared complexes **7** and **8**, the above procedure was modified by the addition of KF or KCN (10 equivalents) to the solution of complex **2** in dichloromethane. The mixture was then stirred for 30 minutes at room temperature before being cooled to 0 ^{o}C and the kinetics experiment started.

Graphical representations of the kinetics of each reaction are given on the following pages.

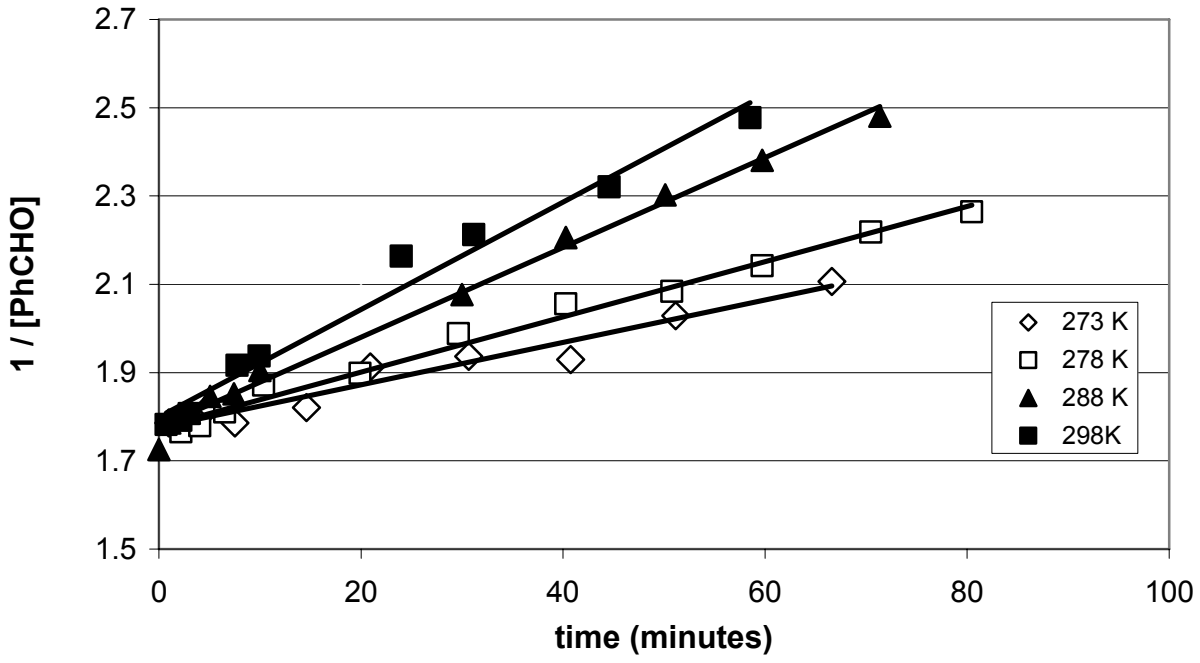
Kinetics experiments using titanium(salen) catalyst 1

First Order Kinetics Plot



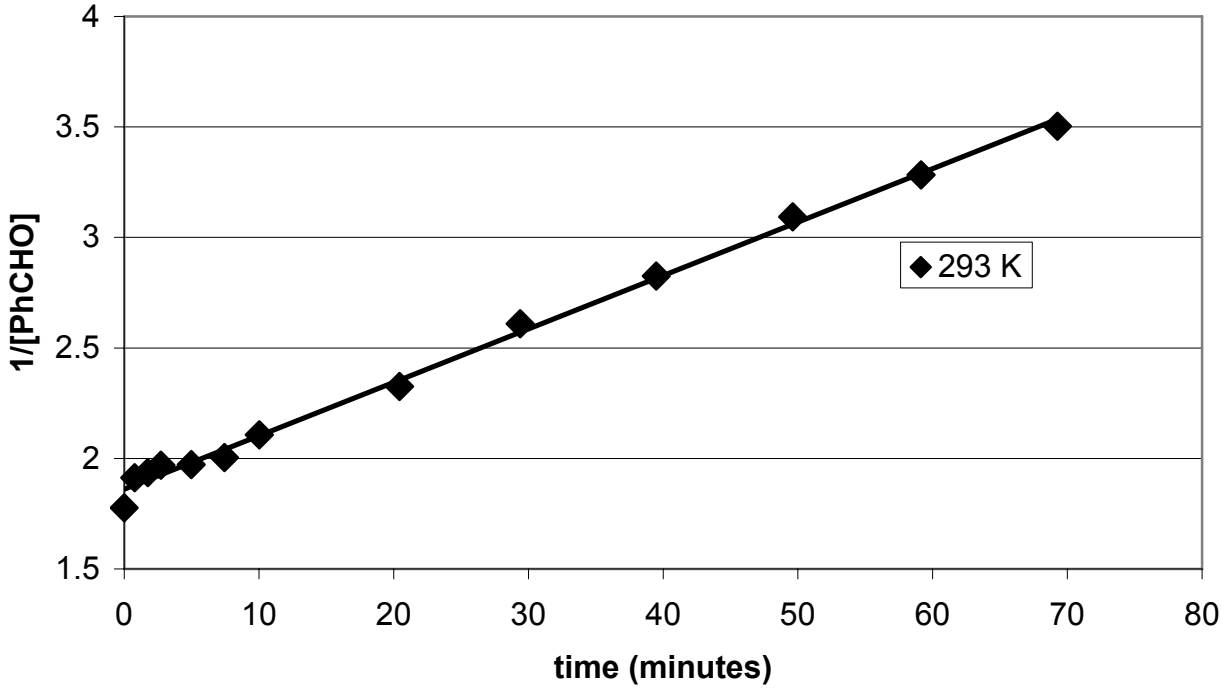
Kinetics experiments using vanadium(V)(salen) sulfate catalyst 2

Second Order Kinetics Plot

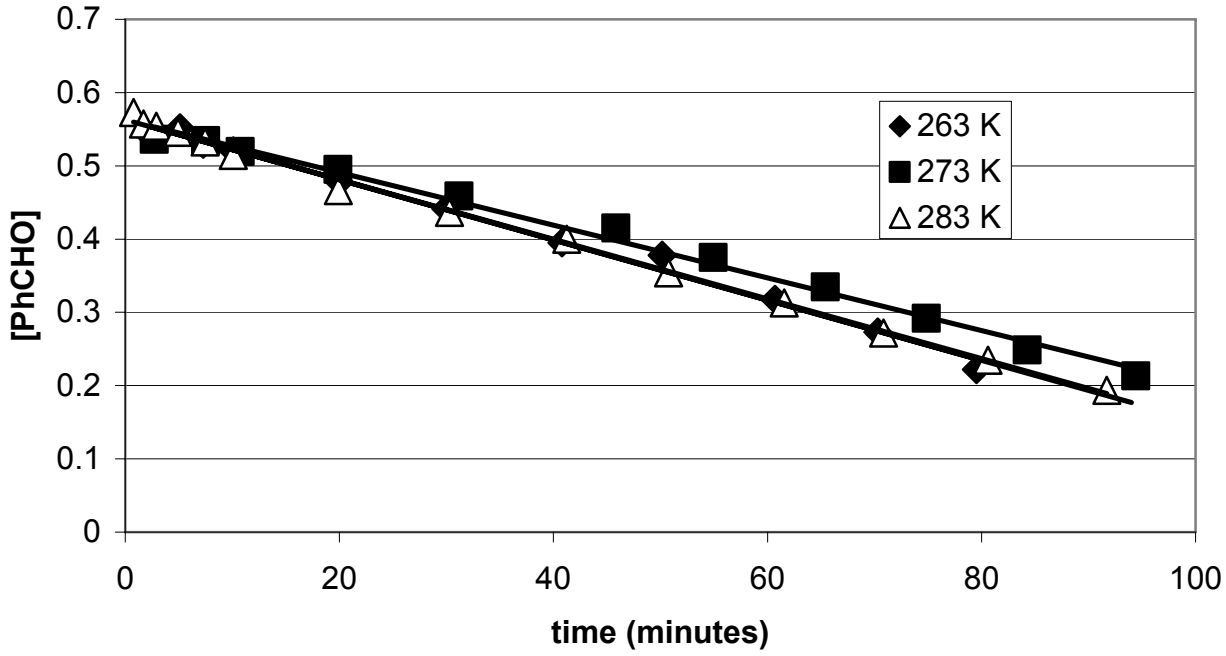


Kinetics experiments using vanadium(V)(salen) tetrafluoroborate catalyst 3

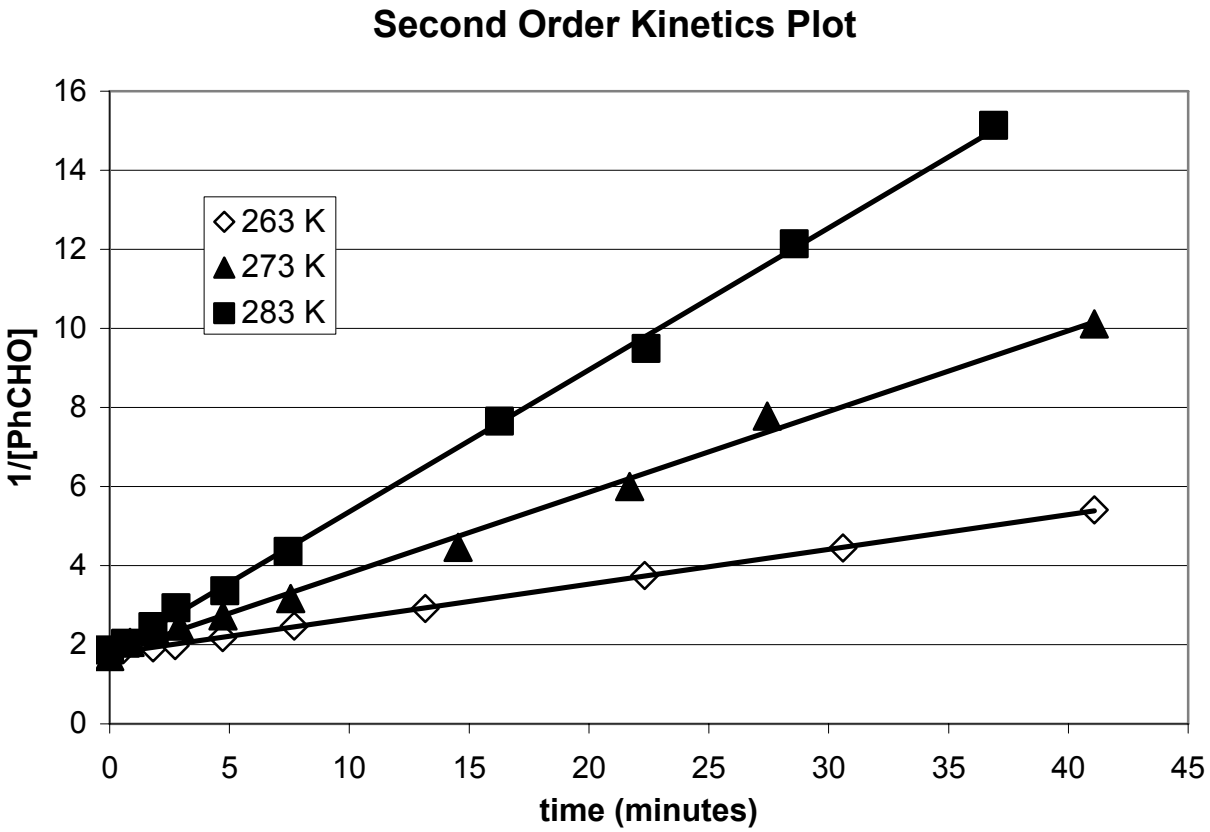
Second Order Kinetics Plot



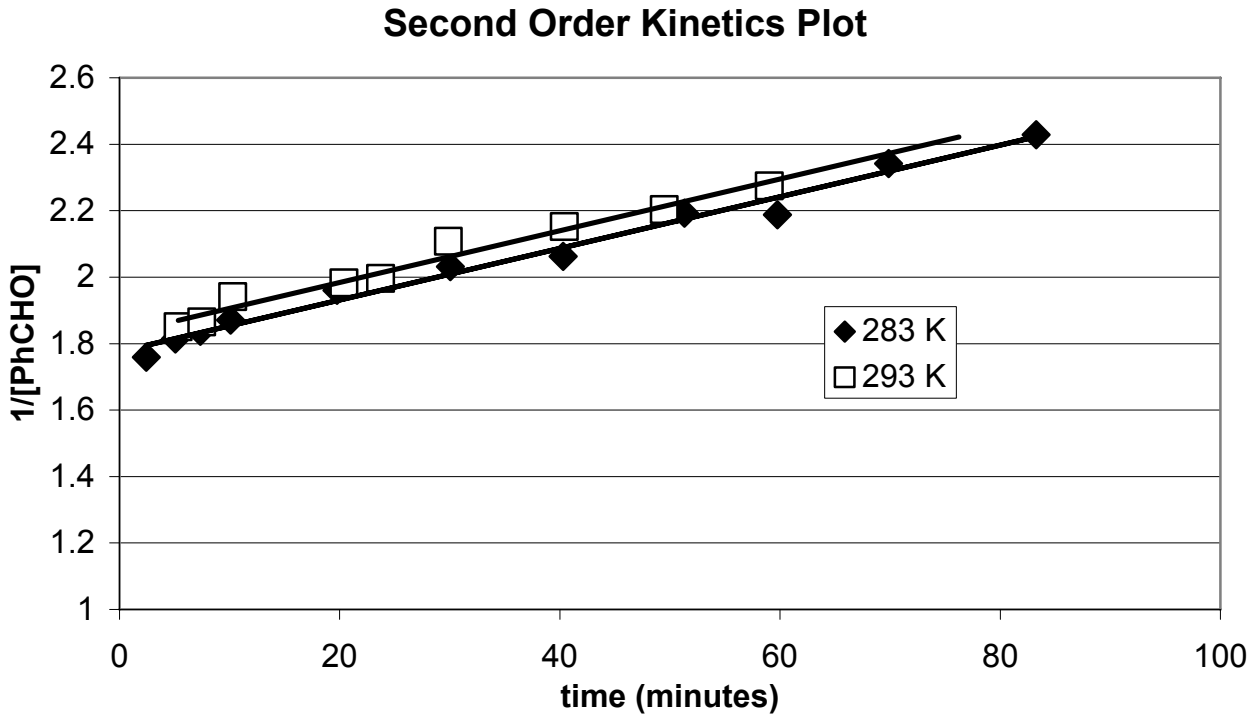
Zero Order Kinetics Plot

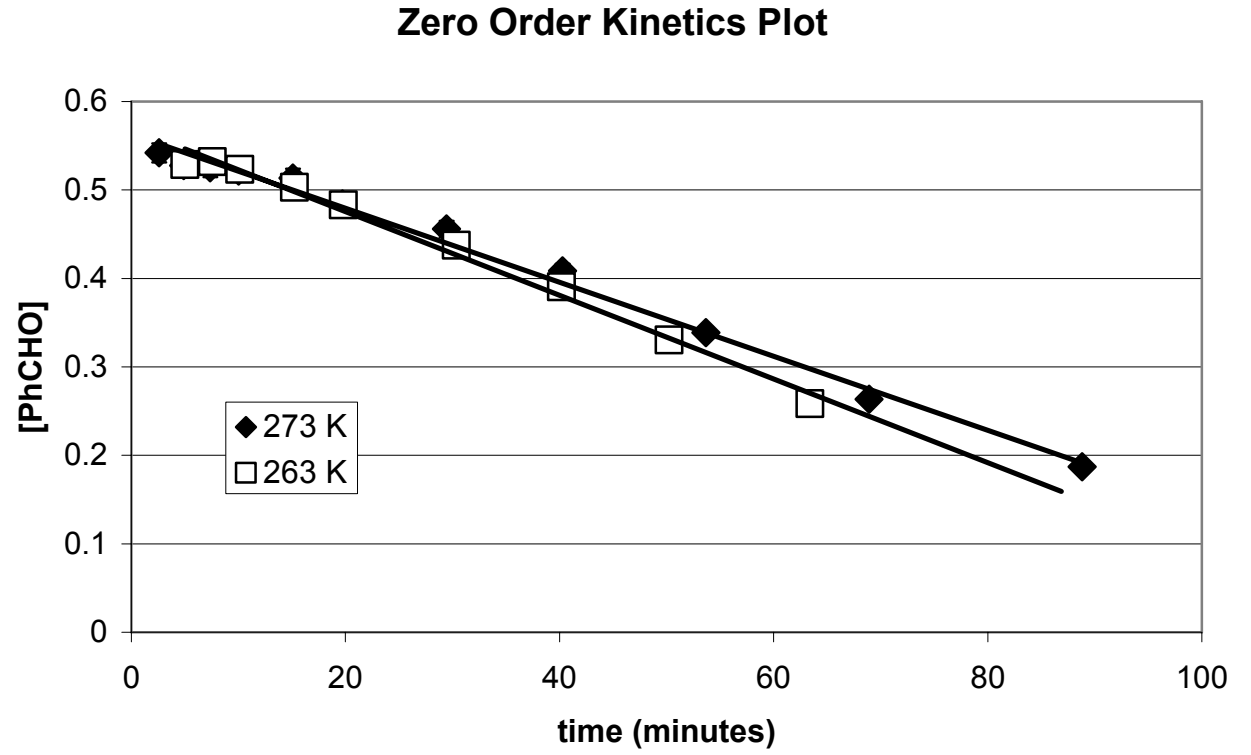


Kinetics experients using vanadium(V)(salen) chloride catalyst 4

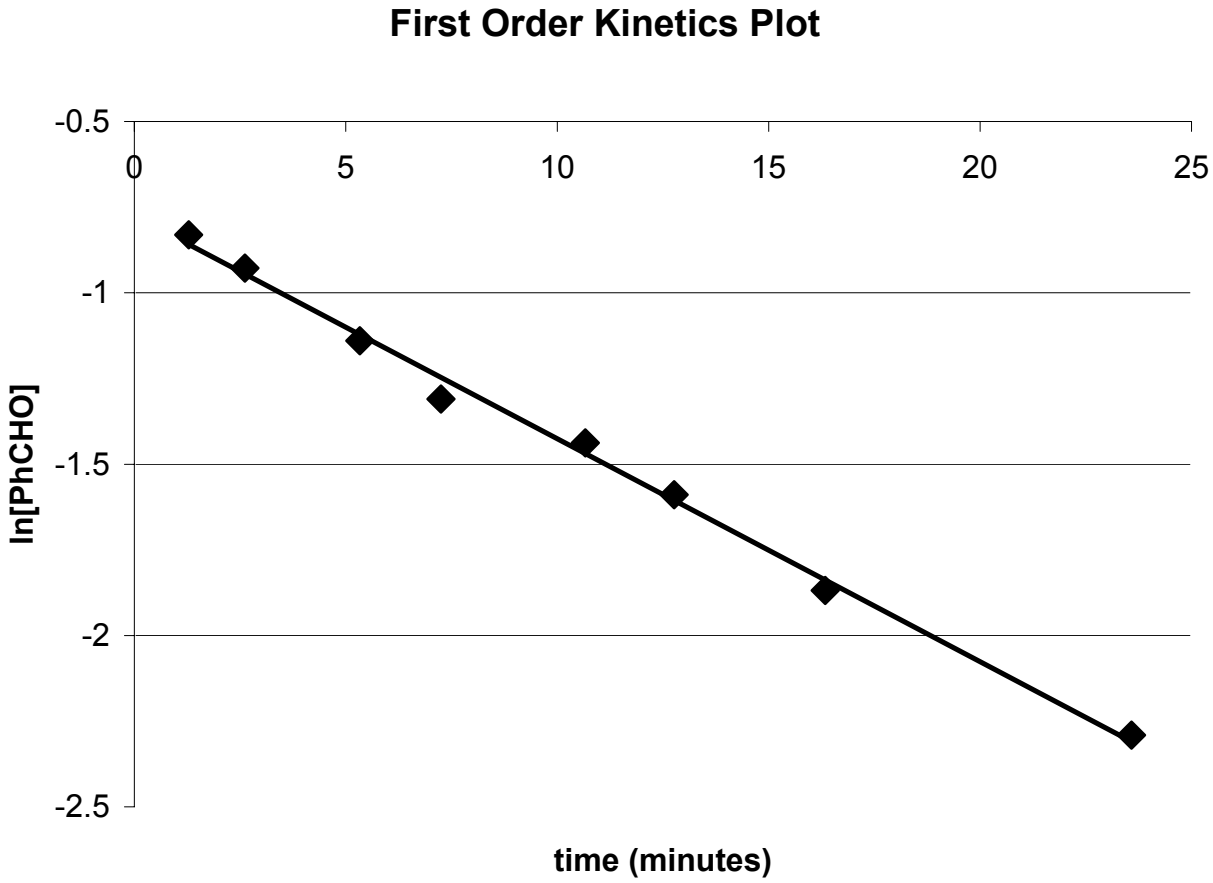


Kinetics experiments using vanadium(V)(salen) bromide catalyst 5





Kinetics experiment using vanadium(V)(salen) fluoride catalyst 7 at 0 °C



Kinetics experiment using vanadium(V)(salen) cyanide catalyst 8 at 0 °C