Supplementary Material (ESI) for Organic & Biomolecular Chemistry

DOSY NMR for Monitoring Self Aggregation of Bifunctional Organocatalysts: Increasing Enantioselectivity with Decreasing Catalyst Concentration

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Electronic Supplementary Information (ESI)

1. General

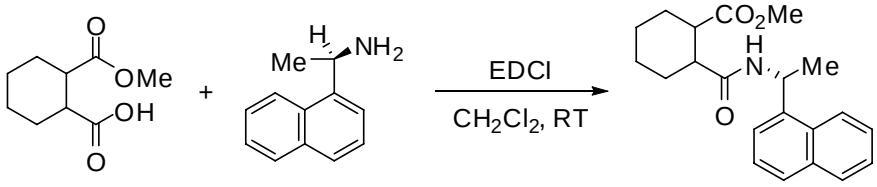
meso-1,2-Cyclohexanedicarbolyic anhydride (**5**), 2-cylclohexene-1-one (**9**) were purchased from Aldrich and used without further purification. The racemic valine-derived azlactone (**7**) was prepared from racemic valine according to the literature procedure.[1] Alcohols (methanol and allyl alcohol) and thiols (thiophenol and 2-methoxy thiophenol) were purchased from Aldrich and used without further purification. Thiourea catalysts (**1**[3], **2**[3], **3a**[2], **3b**[2]) and squaramide catalysts (**4a**[4], **4b**[4]) were prepared according to the literature procedure.

2. Procedure for the methanolysis of *meso*-1,2-cyclohexanedicarboxylic anhydride (5)

Methanol (202 μL, 5 mmol) was added dropwise to a stirred solution of anhydrides (**5**, 0.5 mmol) and catalysts (**1, 2 , 3a and 4a**) (10 mol%) in appropriate solvents (2.5 mL - 40 mL) at the temperature indicated in Figure 2 (Table S1, S2, S3 and S4). The reaction mixture was stirred at that temperature until the starting material was consumed, as indicated by TLC analysis. The reaction was quenched by adding HCl (1N, 3 mL) in one portion. The aqueous phase was extracted with EtOAc (2 × 100 mL). The organic phase was dried ($MgSO_4$), filtered, and concentrated *in vacuo* to yield the crude product. Purification by column chromatography (EtOAc:Hexane = 1:4) gave hemiester product (**6**)

The enantiomeric excess (*ee*) of the product was determined by HPLC analysis of a diastereomeric mixture of the corresponding amide-ester prepared from hemiester **6** according to the literature procedure[5] (Scheme S1).

Scheme S1



3. Procedure for the DKR reaction of racemic valine-derived azalactone (7)

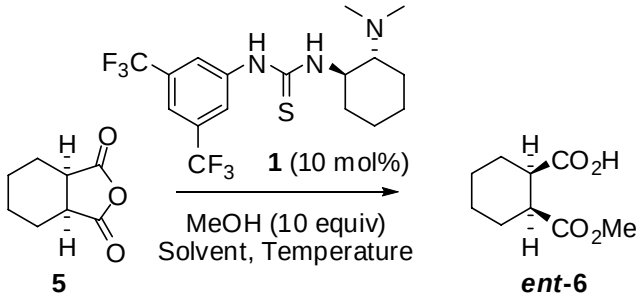
Allyl alcohol (68 μL, 1 mmol) was added to a stirred solution of the azlactones (**7**, 0.5 mmol) and catalyst (**3b** and **4b**) (10 mol%) in CH_2Cl_2 (5 mL - 50 mL) at the temperature indicated in Figure 3 (Table S5 & S6). The reaction mixture was stirred at that temperature until the starting material was consumed, as indicated by TLC analysis. The reaction was quenched by adding HCl (1N, 3 mL) in one portion. The aqueous phase was extracted with EtOAc (2 × 100 mL). The organic phase was dried ($MgSO_4$), filtered, and concentrated *in vacuo* to yield the crude product. Purification by column chromatography (EtOAc:Hexane = 1:4) gave *N*-benzoylated α-amino allyl ester (**8)**.

4. Procedure for the conjugate addition of aryl thiol to 2-cyclohexene-1-one (9)

Thiophenol (61 μL, 0.6 mmol) or 2-methoxybenzenethiol (73 μL, 0.6 mmol) was added in one portion to a stirred solution of 2-cylclohexene-1-one (**9**, 0.5 mmol) and thiourea catalyst **3a**(0.25 mol% - 100 mol%) and squaramide catalyst **4a**(0.25 mol% - 10 mol%) in CH_2Cl_2 (0.6 mL - 20 mL) at the temperature indicated in Figure 3 (Table S7 & S8) and Table 1(Table S11 & S12). The reaction mixture was stirred at that temperature until the starting material was consumed, as indicated by TLC analysis. The reaction was quenched by adding HCl (1N, 3 mL) in one portion. The aqueous phase was extracted with EtOAc (2 X 100 mL). The organic phase was dried ($MgSO_4$), filtered, and concentrated *in vacuo* to yield the crude product. Purification by column chromatography (EtOAc:Hexane = 1:4) gave thiol added products (**10** and **12**)

5. HPLC spectra for Figure 2

Table S1. Concentration and temperature effects on enantioselectivity in the desymmetrization of *meso*-anhydride **5** using the catalyst **1** (Figure 2)



5 ***ent*-6**

Entry	Concentration	T (^{o}C)	Time (h)	Yield (%)[b]	% ee[c]
1	THF (40 mL, 0.0125 M)	RT	12	82	92
2	THF (10 mL, 0.05 M)	RT	4	81	85
3	THF (2.5 mL, 0.2 M)	RT	1.6	84	63
4	THF (2.5 mL, 0.2 M)	0 ^{o}C	5	83	55
5	THF (2.5 mL, 0.2 M)	-20 ^{o}C	24	80	51
6	Toluene (40 mL, 0.0125 M)	RT	11	81	61
7	Toluene (10 mL, 0.05 M)	RT	3.5	80	48
8	Toluene (2.5 mL, 0.2 M)	RT	1.2	85	36
9	Toluene (2.5 mL, 0.2 M)	0 ^{o}C	4	83	23
10	Toluene (2.5 mL, 0.2 M)	-20 ^{o}C	22	81	11

[a] Reactions were carried out with **5** (0.5 mmol), MeOH (5 mmol) and **1** (10 mol%, 0.05 mmol). [b] Isolated yields after chromatographic purification. [c] ee value of ***ent*-6** was determined by HPLC.

HPLC spectra for Table S1.

The ee value was determined by the HPLC analysis (Hypersil, Hexanes : IPA (40 : 1), 1 mL/min, *t*(minor) = 8.30 min, *t*(major) = 11.33 min) of the diastereomeric mixture of the corresponding amide-ester, which was prepared as depicted in Scheme S1.

Table S1. Entry 1

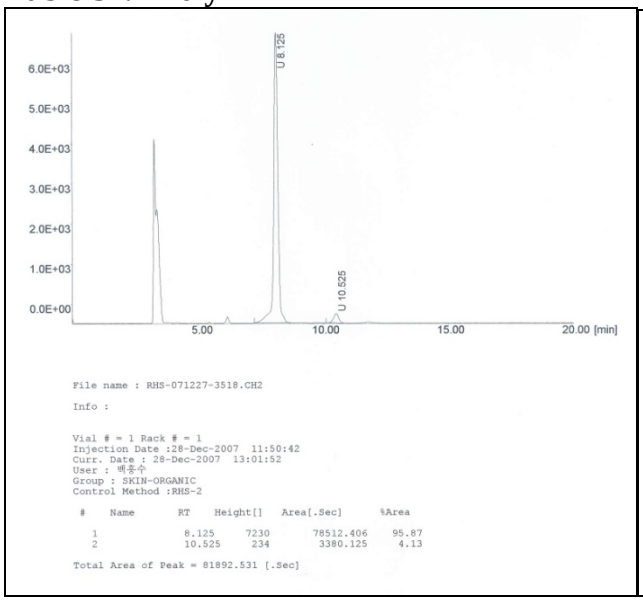


Table S1. Entry 2

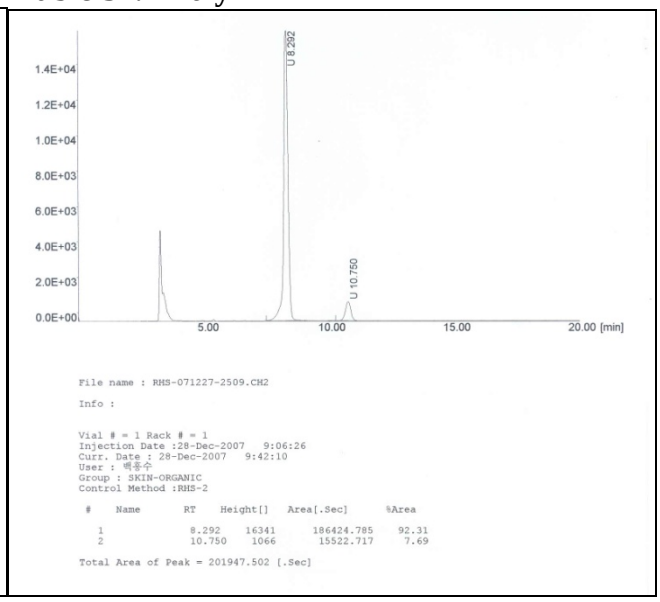


Table S1. Entry 3

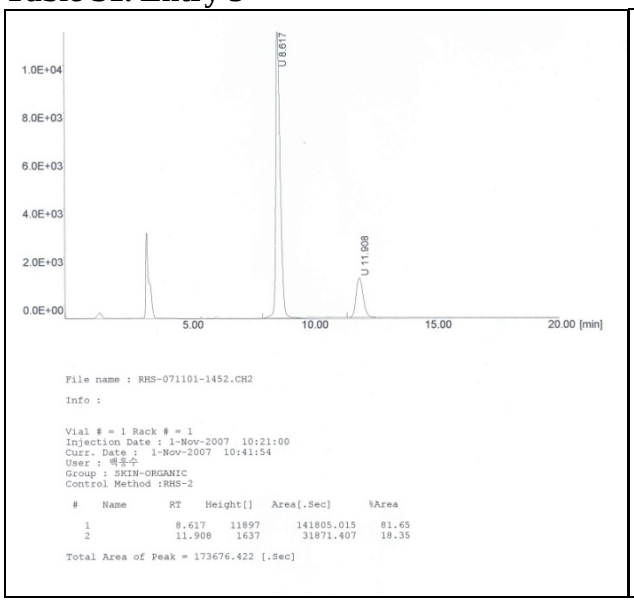


Table S1. Entry 4

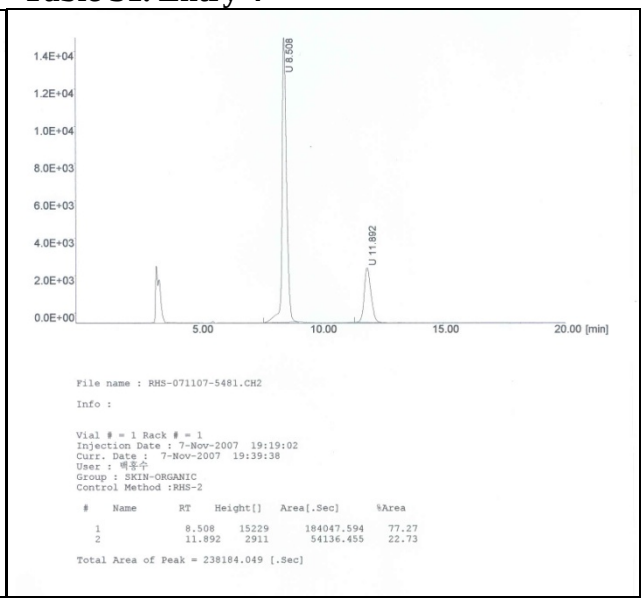
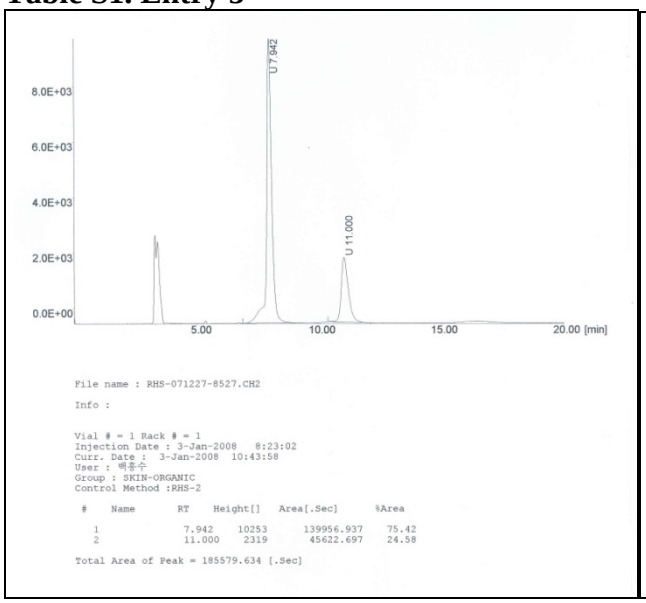


Table S1. Entry 5



File name : RHS-071227-8527.CH2

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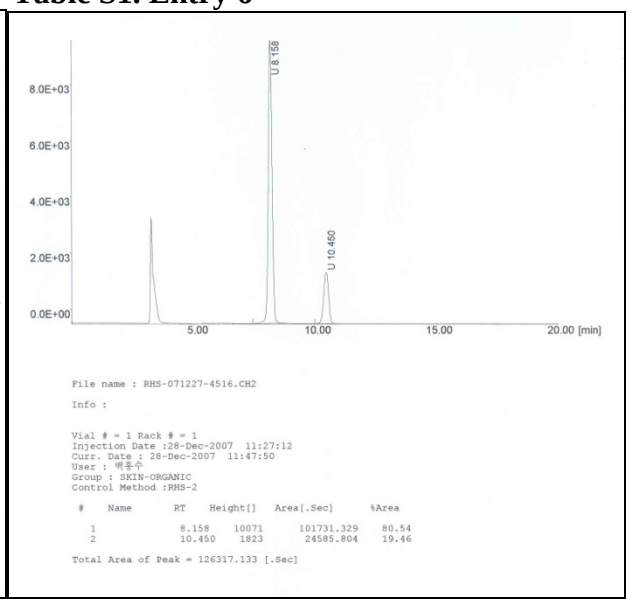
Curr. Date : 3-Jan-2008 10:43:58
User : 백홍수
Group : SKIN-ORGANIC
Control Method :RHS-2

#	Name	RT	Height[]	Area[.Sec]	%Area
1		7.942	10253	139956.937	75.42
2		11.000	2319	45622.697	24.58

Total Area of Peak = 185579.634 [.Sec]

Table S1. Entry 6



File name : RHS-071227-4516.CH2

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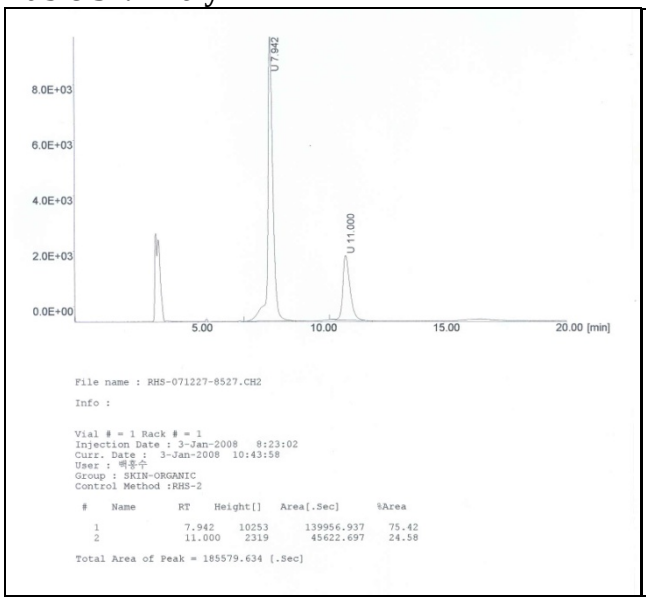
Curr. Date : 28-Dec-2007 11:47:50
User : 백홍수
Group : SKIN-ORGANIC
Control Method :RHS-2

#	Name	RT	Height[]	Area[.Sec]	%Area
1		8.158	10071	101731.329	80.54
2		10.450	1823	24585.804	19.46

Total Area of Peak = 126317.133 [.Sec]

Table S1. Entry 7



File name : RHS-071227-8527.CH2

Info :

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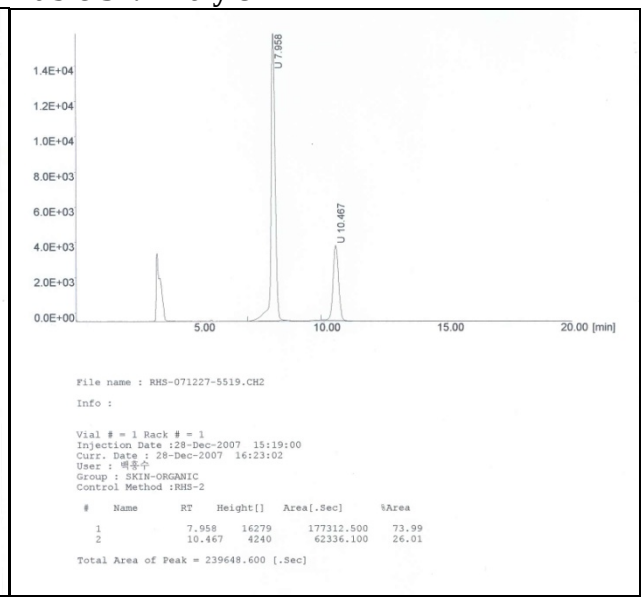
Injection Date : 3-Jan-2008 8:23:02
Curr. Date : 3-Jan-2008 10:43:58
User : 백홍수
Group : SKIN-ORGANIC
Control Method :RHS-2

#	Name	RT	Height[]	Area[.Sec]	%Area
1		7.942	10253	139956.937	75.42
2		11.000	2319	45622.697	24.58

Total Area of Peak = 185579.634 [.Sec]

Table S1. Entry 8



File name : RHS-071227-5519.CH2

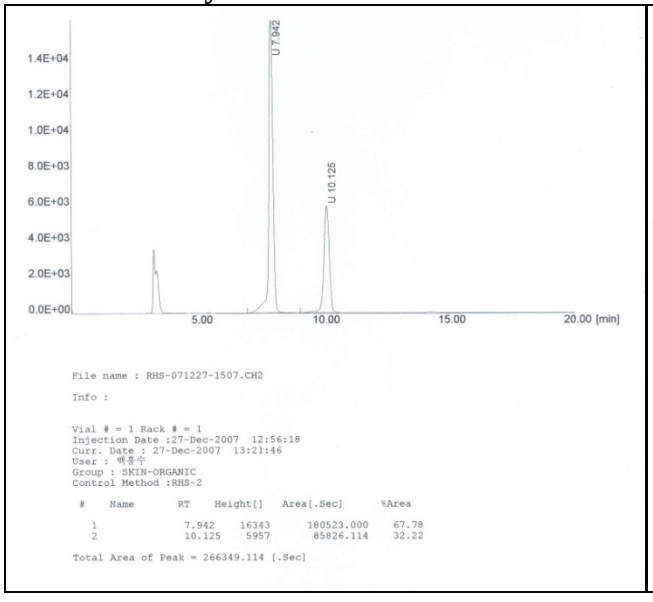
Info :

Vial # = 1 Rack # = 1
Injection Date :28-Dec-2007 15:19:00
Curr. Date : 28-Dec-2007 16:23:02
User : 백홍수
Group : SKIN-ORGANIC
Control Method :RHS-2

#	Name	RT	Height[]	Area[.Sec]	%Area
1		7.958	16279	177312.500	73.99
2		10.467	4240	62336.100	26.01

Total Area of Peak = 239648.600 [.Sec]

Table S1. Entry 9



File name : RHS-071227-1507.CH2

Info :

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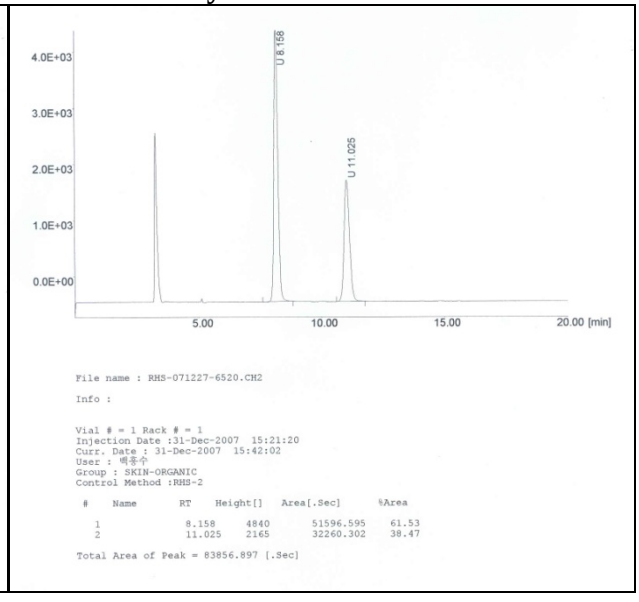
Injection Date :27-Dec-2007 12:56:18
Curr. Date : 27-Dec-2007 13:21:46
User : 백홍수
Group : SKIN-ORGANIC
Control Method :RHS-2

#	Name	RT	Height[]	Area[.Sec]	%Area
1		7.942	16343	180523.000	67.78
2		10.125	5957	85826.114	32.22

Total Area of Peak = 266349.114 [.Sec]

Table S1. Entry 10



File name : RHS-071227-6520.CH2

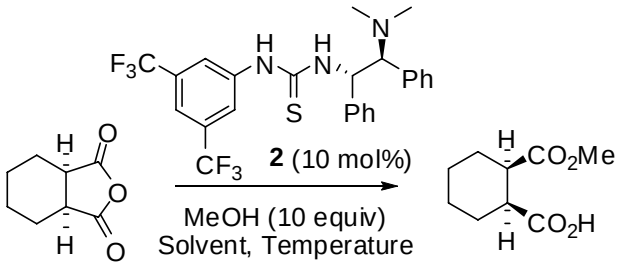
Info :

Vial # = 1 Rack # = 1
Injection Date :31-Dec-2007 15:21:20
Curr. Date : 31-Dec-2007 15:42:02
User : 백홍수
Group : SKIN-ORGANIC
Control Method :RHS-2

#	Name	RT	Height[]	Area[.Sec]	%Area
1		8.158	4840	51596.595	61.53
2		11.025	2165	32260.302	38.47

Total Area of Peak = 83856.897 [.Sec]

Table S2. Concentration and temperature effect on enantioselectivity in the desymmetrization of *meso*-anhydride **5** using the catalyst **2** (Figure 2)



5 **6**

Entry	Concentration	T (^{o}C)	Time (h)	Yield (%)[b]	% ee[c]
1	THF (40 mL, 0.0125 M)	RT	17	89	94
2	THF (10 mL, 0.05 M)	RT	9.5	87	93
3	THF (2.5 mL, 0.2 M)	RT	2	91	89
4	THF (2.5 mL, 0.2 M)	0 ^{o}C	4	90	89
5	THF (2.5 mL, 0.2 M)	-20 ^{o}C	9	89	83

[a] Reactions were carried out with **5** (0.5 mmol), MeOH (5 mmol) and **2** (10 mol%, 0.05 mmol). [b] Isolated yields after chromatographic purification. [c] ee value of **6** was determined by HPLC.

HPLC spectra for Table S2.

Table S2. Entry 1

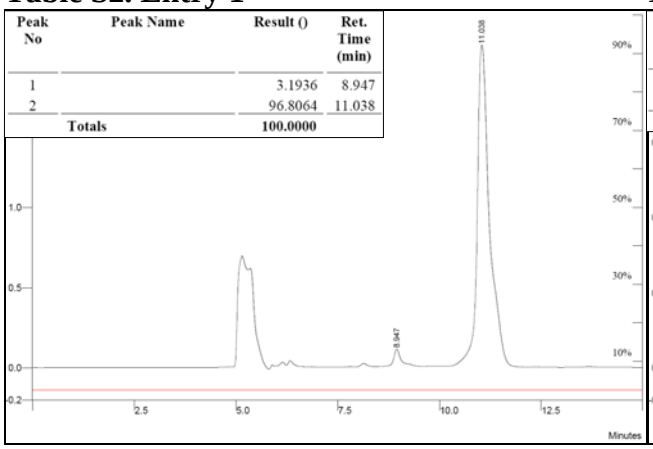


Table S2. Entry 2

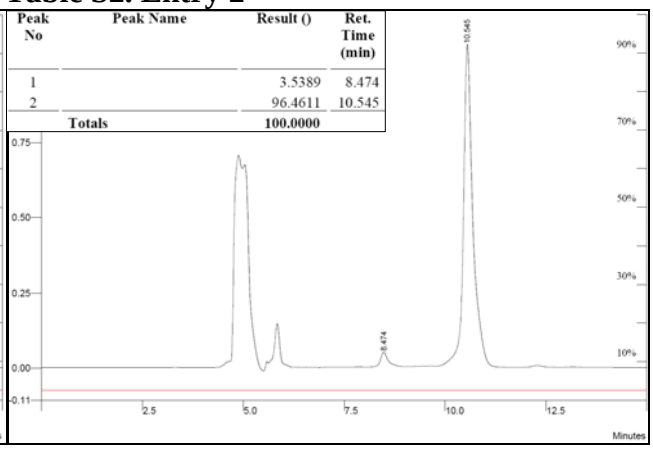


Table S2. Entry 3

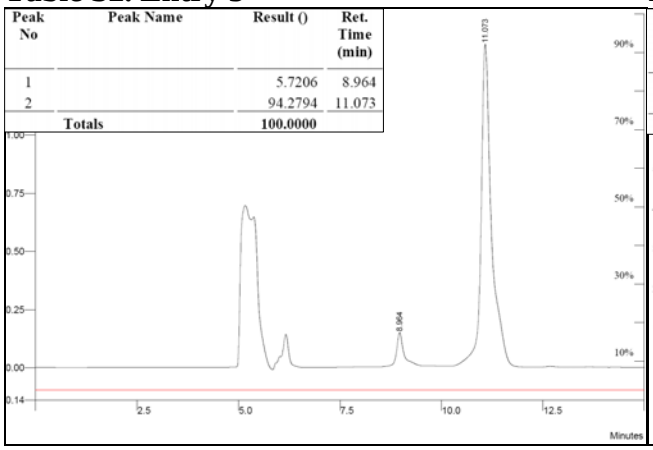


Table S2. Entry 4

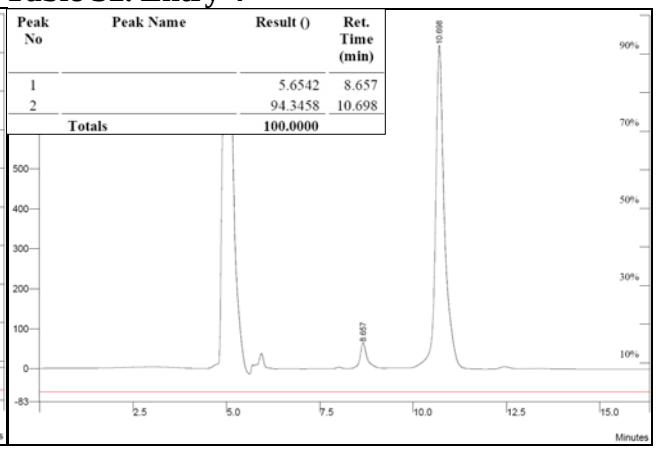


Table S2. Entry 5

Peak No	Peak Name	Result ()	Ret. Time (min)
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2		91.6404	11.089
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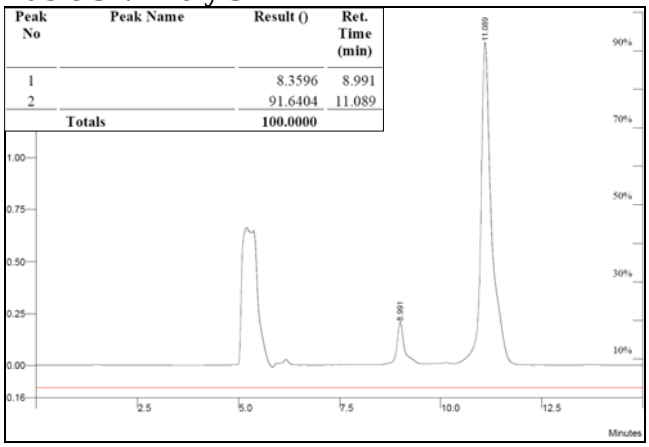
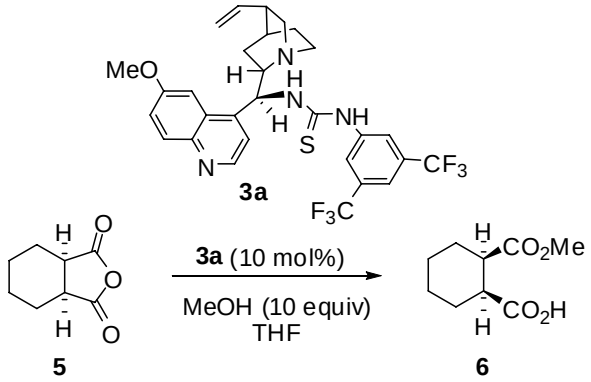


Table S3. Concentration and temperature effects on enantioselectivity in the methanolytic desymmetrization of *meso*-anhydride **5** using the catalyst **3a** (Figure 2)



Entry	Concentration	T (^{o}C)	Time (h)	Yield (%)[b]	% ee[c]
1	THF (40 mL, 0.0125 M)	RT	10	84	95
2	THF (10 mL, 0.05 M)	RT	7	83	93
3	THF (2.5 mL, 0.2 M)	RT	0.6	82	82
4	THF (2.5 mL, 0.2 M)	0 ^{o}C	5.5	81	81
5	THF (2.5 mL, 0.2 M)	-20 ^{o}C	11	80	77

[a] Reactions were carried out with **5** (0.5 mmol), MeOH (5 mmol) and **3a** (10 mol%, 0.05 mmol). [b] Isolated yields after chromatographic purification. [c] Ee value of **6** was determined by HPLC.

HPLC spectra for Table S3.

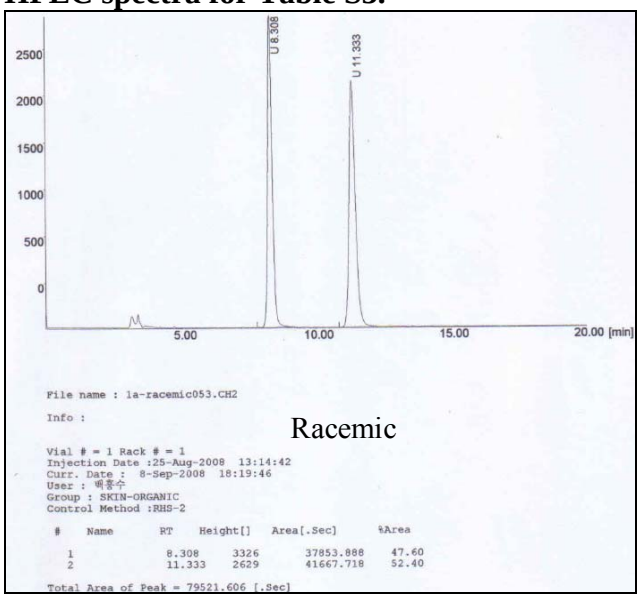


Table S3. Entry 1

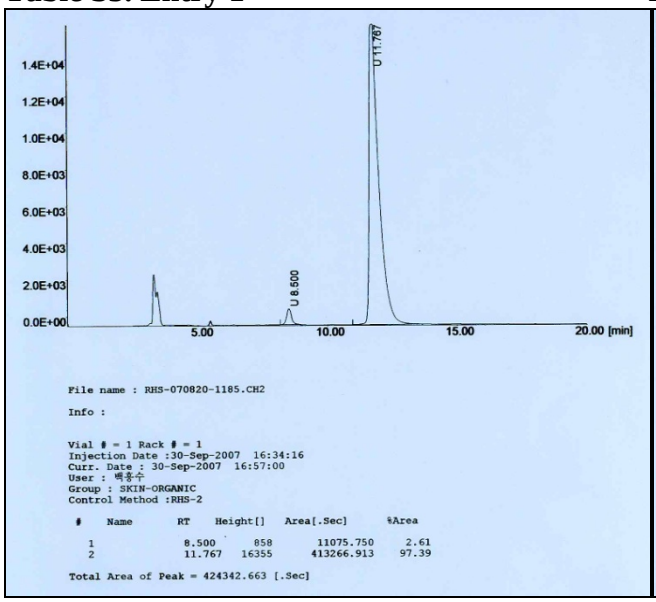


Table S3. Entry 2

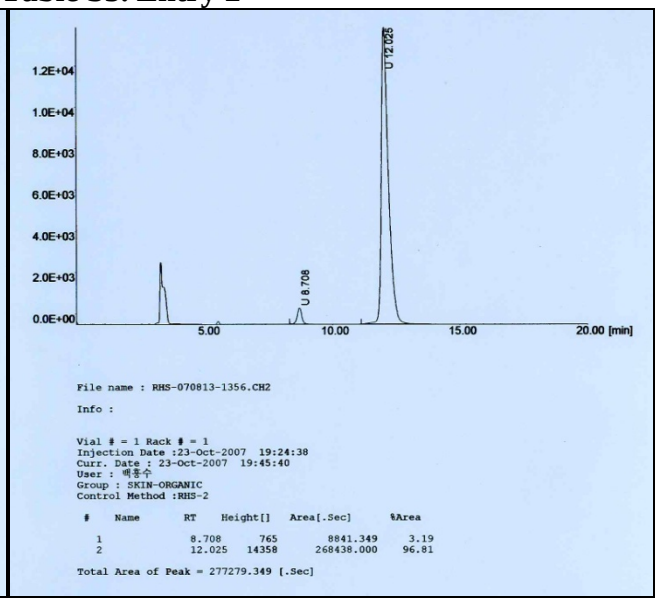


Table S3. Entry 3

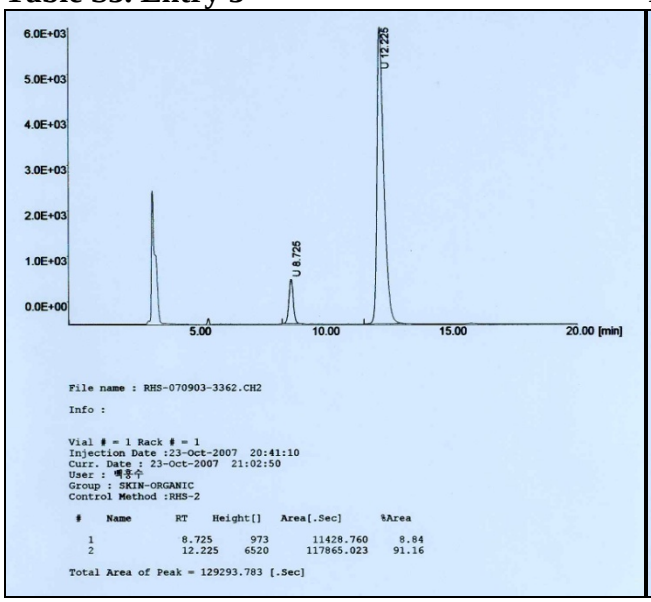


Table S3. Entry 4

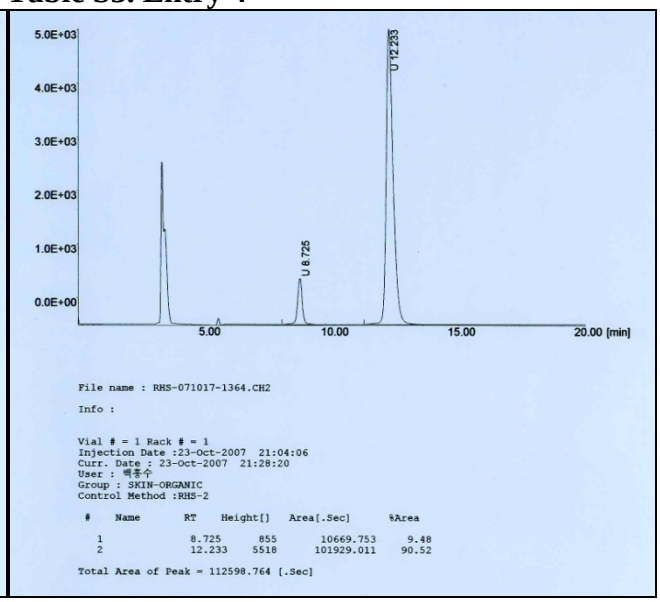


Table S3. Entry 5

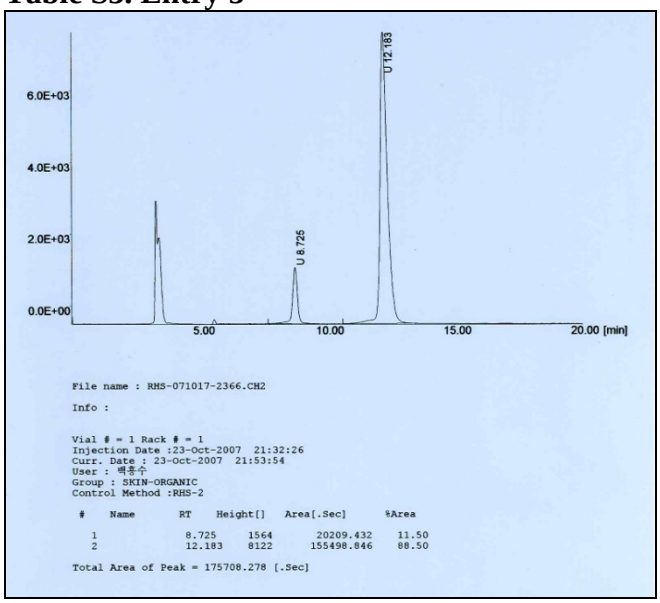
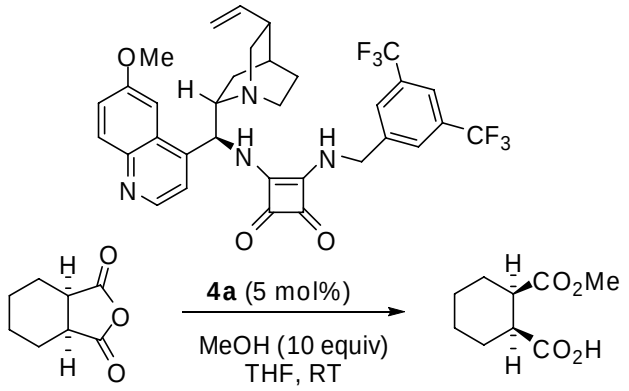


Table S4. Concentration and temperature effects on enantioselectivity in the methanolytic desymmetrization of *meso*-anhydride **5** using the catalyst **4a** (Figure 2)



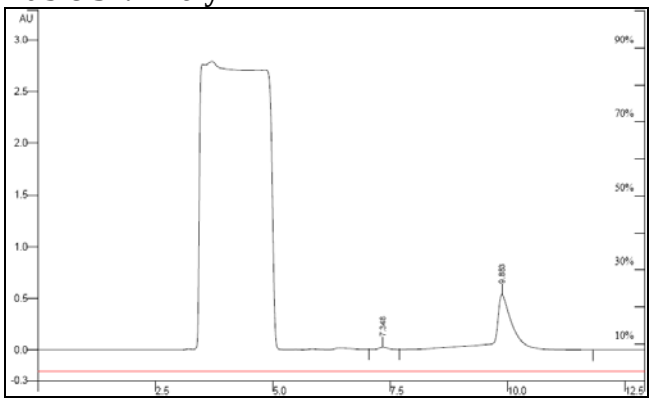
5 **6**

Entry	Concentration	T (^{o}C)	Time (h)	Yield (%)[b]	% ee[c]
1	THF (10 mL)	RT	5	88	96
2	THF (5 mL)	RT	2.5	86	94
3	THF (2.5 mL)	RT	1	85	91

[a] Reactions were carried out with **5** (0.5 mmol), MeOH (5 mmol) and **4a** (5 mol%, 0.025 mmol). [b] Isolated yields after chromatographic purification. [c] Ee value of **6** was determined by HPLC.

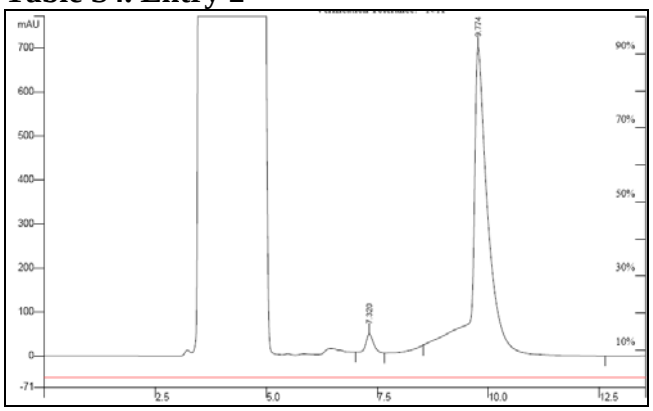
HPLC spectra for Table S4.

Table S4. Entry 1



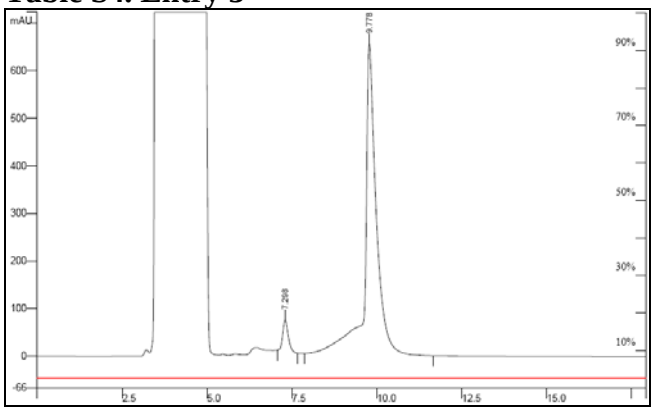
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	1.7635	7.348	2484306	10.4
2	98.2365	9.883	138387040	17.3
	100.0000		**140871344**	

Table S4. Entry 2



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	3.1719	7.320	4790105	10.2
2	96.8281	9.774	146226704	16.4
	100.0000		**151016816**	

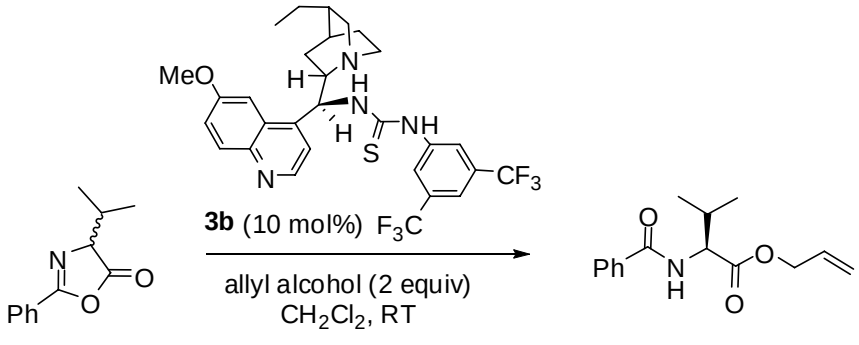
Table S4. Entry 3



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	4.5564	7.298	7328855	9.8
2	95.4436	9.778	153517808	16.0
	100.0000		**160846656**	

6. HPLC spectra for Figure 3

Table S5. Concentration effect on enantioselectivity in the DKR reaction of *rac*-azlactone **7** using the catalyst **3b** (Figure 3)



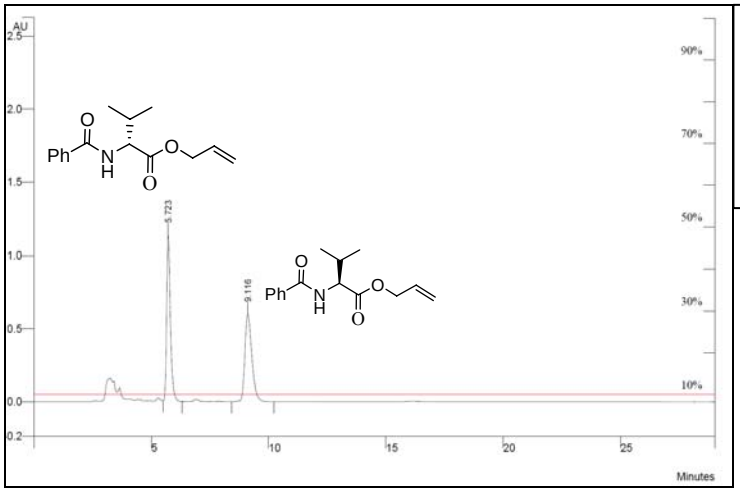
rac-**7** **8**

Entry	Concentration	T (^{o}C)	Time (h)	Yield (%)	% ee[b]
1	CH_2Cl_2 (5 mL, 0.1 M)	RT	12	91	77.6
2	CH_2Cl_2 (2.5 mL, 0.2 M)	RT	12	93	76.2
3	CH_2Cl_2 (1.25 mL, 0.4 M)	RT	12	93	75.4
4	CH_2Cl_2 (0.83 mL, 0.6 M)	RT	12	93	74.5
5	CH_2Cl_2 (0.625 mL, 0.8 M)	RT	12	97	74
6	CH_2Cl_2 (0.5 mL, 1.0 M)	RT	12	98	72.7

[a] Reactions were carried out with *rac*-**7** (0.5 mmol), 2 equiv of allyl alcohol (2 equiv, 1 mmol) and **3b** (10 mol%, 0.05 mmol) in CH_2Cl_2 at room temperature. [b] Ee value of **8** was determined by HPLC.

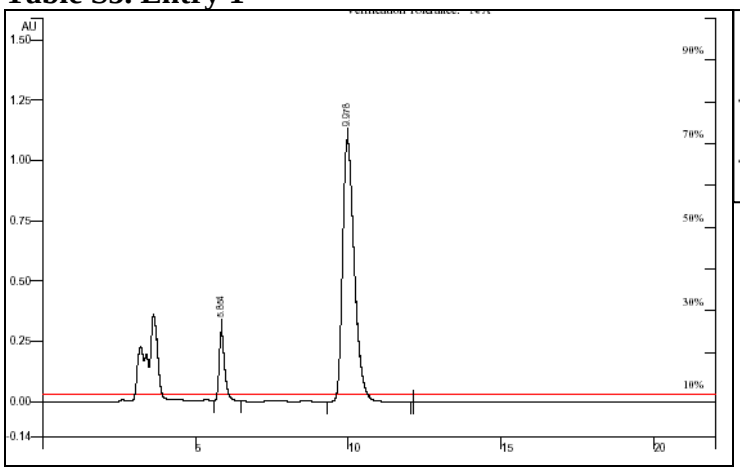
HPLC spectra for Table S5.

The ee value was determined by the HPLC analysis (Chiralpak OD-H, Hexanes : IPA (9 : 1), 1 mL/min, UV detection at 220 nm, *t*(minor) = 5.70 min, *t*(major) = 9.12 min).



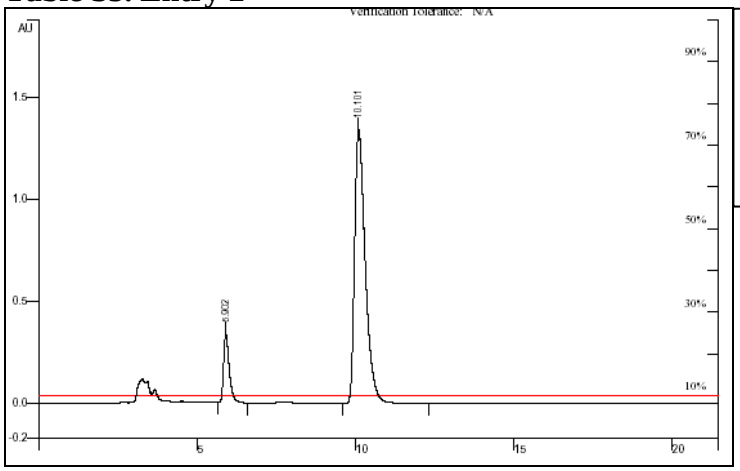
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	50.2644	5.723	125366640	9.7
2	49.7356	9.116	124047880	18.8
	100.0000		**249414528**	

Table S5. Entry 1



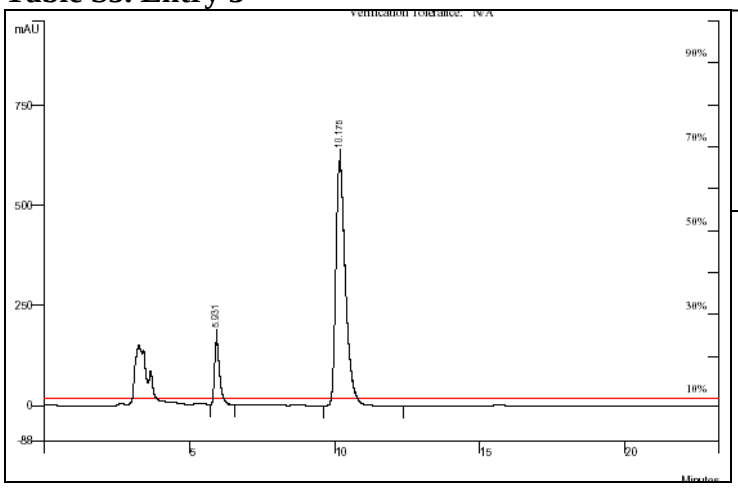
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	11.1874	5.854	36536100	11.0
2	88.8126	9.978	290046400	24.3
	100.0000		326582496	

Table S5. Entry 2



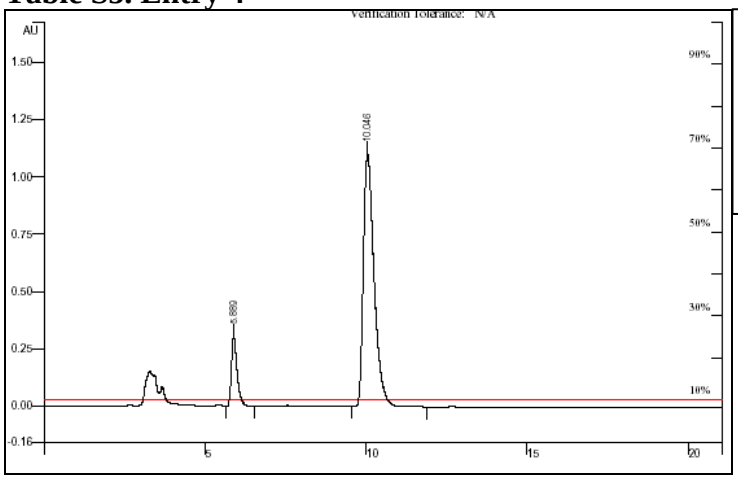
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	11.8875	5.902	42144480	11.0
2	88.1125	10.101	312382304	21.1
	100.0000		354526784	

Table S5. Entry 3



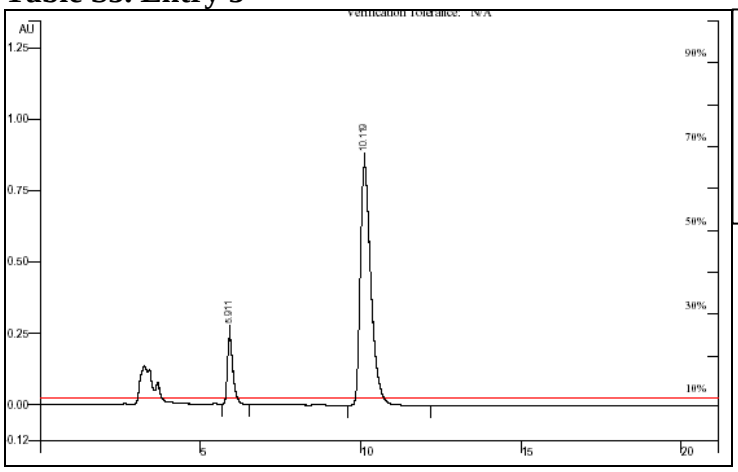
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	12.2770	5.931	19776174	10.8
2	87.7230	10.175	141306960	20.7
	100.0000		161083136	

Table S5. Entry 4



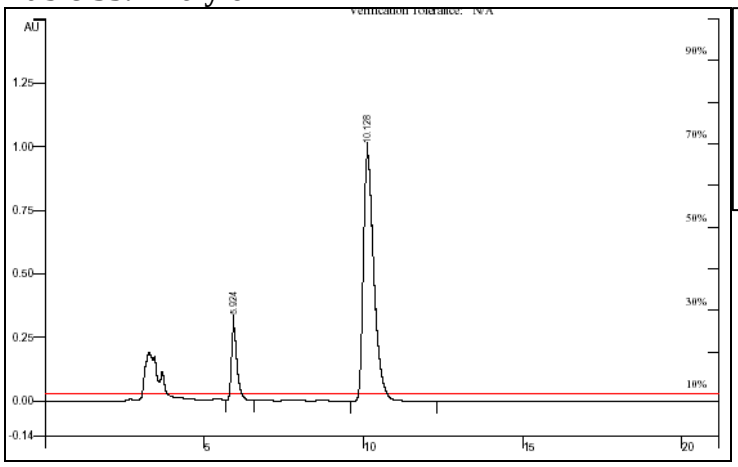
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	12.7687	5.889	37520152	10.8
2	87.2313	10.046	256324864	20.9
	100.0000		**293845024**	

Table S5. Entry 5



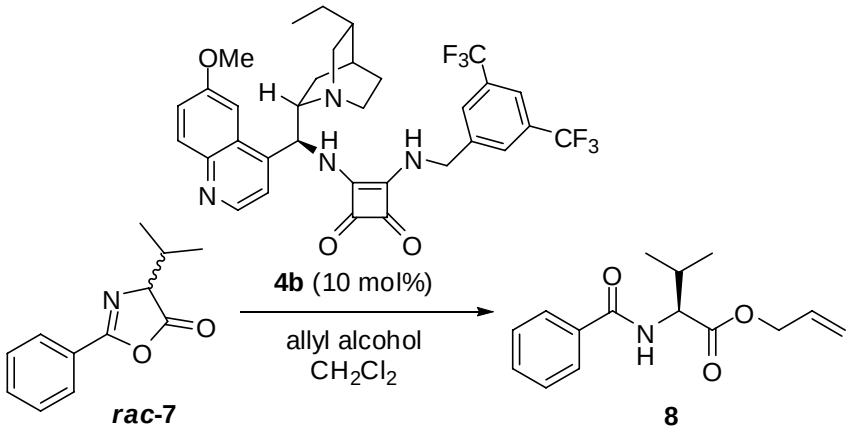
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	13.0189	5.911	29038306	10.8
2	86.9811	10.119	194008416	20.8
	100.0000		**223046720**	

Table S5. Entry 6



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	13.6472	5.924	35600780	10.8
2	86.3528	10.128	225263488	20.9
	100.0000		**260864272**	

Table S6. Concentration effect on enantioselectivity in the DKR reaction of *rac*-azlactone **7** using the catalyst **4b** (Figure 3) [6]

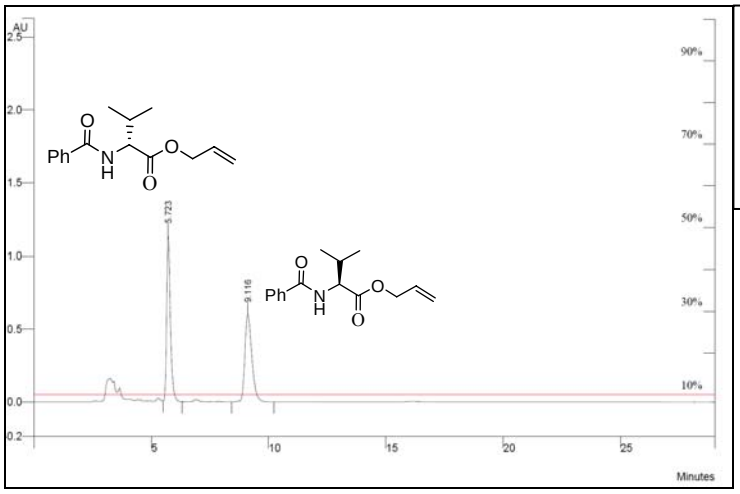


Entry	Concentration	T (^{o}C)	Time (h)	Yield (%)	% ee[b]
1	CH_2Cl_2 (0.1 M)	rt	12	84	88
2	CH_2Cl_2 (0.2 M)	rt	12	86	87
3	CH_2Cl_2 (0.4 M)	rt	12	89	87
4	CH_2Cl_2 (0.6 M)	rt	12	91	86
5	CH_2Cl_2 (0.8 M)	rt	12	94	85
6	CH_2Cl_2 (1.0 M)	rt	12	98	84

[a] Reactions were carried out with *rac*-7 (0.5 mmol), 2 equiv of allyl alcohol (2 equiv, 1 mmol) and **4b** (10 mol%, 0.05 mmol) in CH_2Cl_2 at room temperature. [b] ee value of **8** was determined by HPLC.

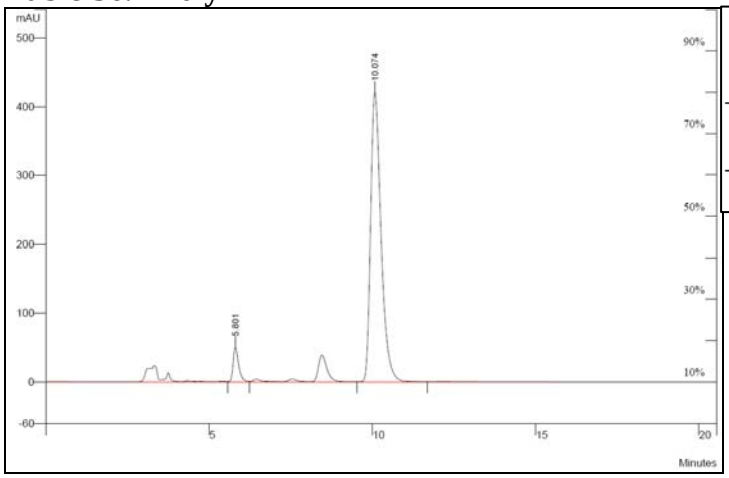
HPLC spectra for Table S6.

The ee value was determined by the HPLC analysis (Chiralpak OD-H, Hexanes : IPA (9 : 1), 1 mL/min, UV detection at 220 nm, *t*(minor) = 5.70 min, *t*(major) = 9.12 min).



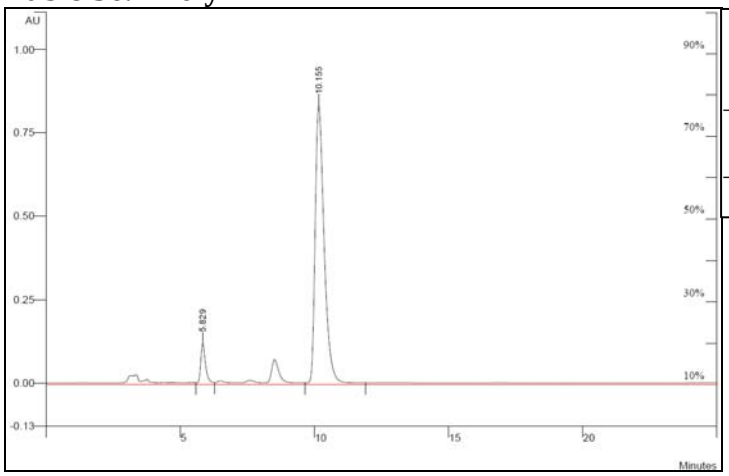
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	50.2644	5.723	125366640	9.7
2	49.7356	9.116	124047880	18.8
	100.0000		**249414528**	

Table S6. Entry 1



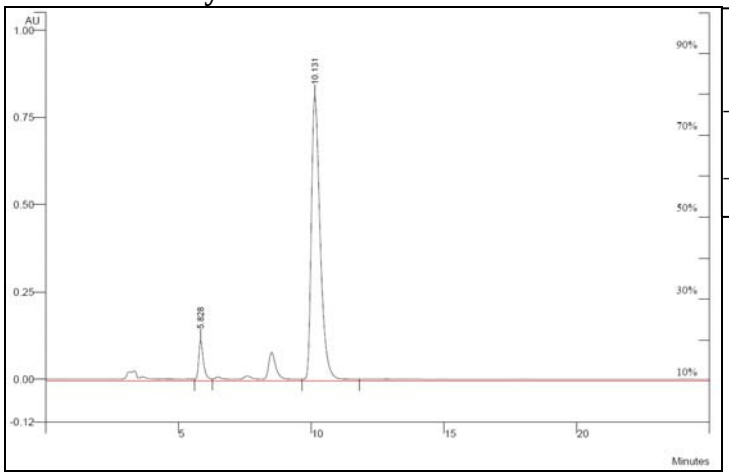
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	5.7818	5.801	5721267	10.5
2	94.2182	10.074	93231992	20.0
	100.0000		**98953256**	

Table S6. Entry 2



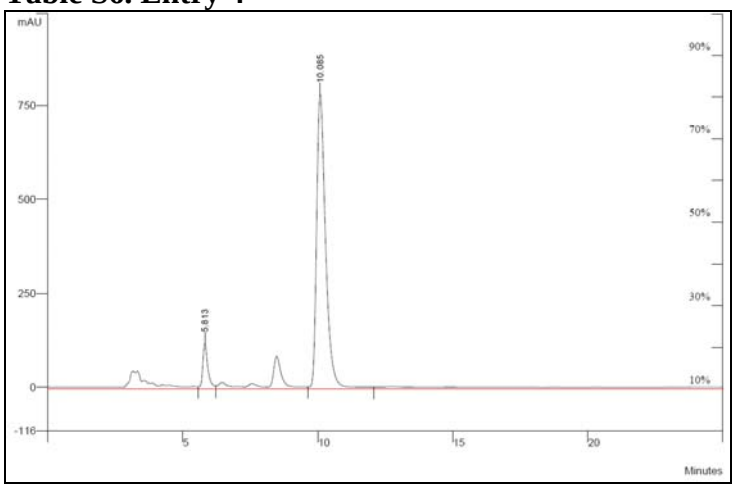
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	6.7419	5.829	13868503	10.6
2	93.2581	10.155	191839008	20.9
	100.0000		**205707504**	

Table S6. Entry 3



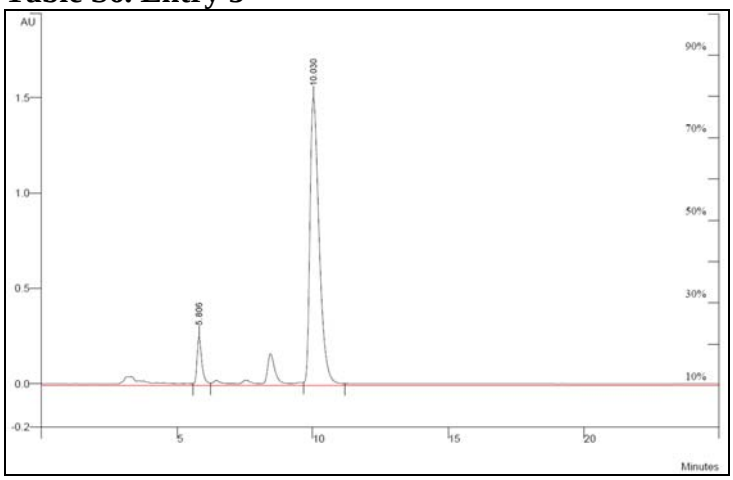
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	6.5451	5.828	12991029	10.6
2	93.4549	10.131	185493888	20.7
	100.0000		**198484912**	

Table S6. Entry 4



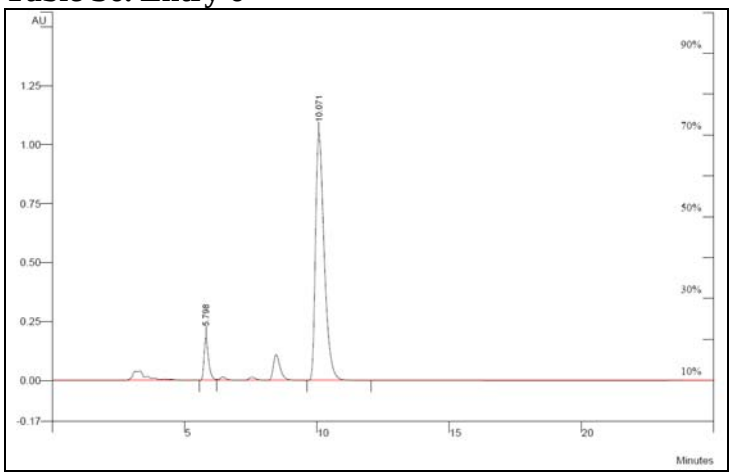
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	7.1164	5.813	13481109	10.7
2	92.8836	10.085	175957072	20.4
	100.0000		**189438176**	

Table S6. Entry 5



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	7.5636	5.806	28478024	10.5
2	92.4364	10.030	348035456	21.3
	100.0000		**376513472**	

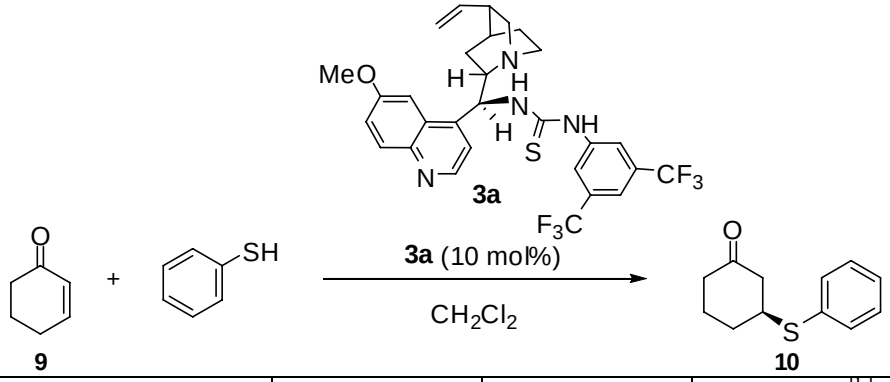
Table S6. Entry 6



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	8.0098	5.798	20840232	10.6
2	91.9902	10.071	239342352	20.7
	100.0000		**260182592**	

7. HPLC spectra for Figure 4

Table S7. Concentration and temperature effect on enantioselectivity in the conjugate addition of benzene thiol to **9** using the catalyst **3a** (Figure 4)



Entry	Concentration	T (^{o}C)	Time (h)	Yield (%)[b]	% ee[c]
1	CH_2Cl_2 (1 mL, 0.5 M)	rt	2	83	65
2	CH_2Cl_2 (2.5 mL, 0.2 M)	rt	4	79	75
3	CH_2Cl_2 (5 mL, 0.1 M)	rt	6	81	79
4	CH_2Cl_2 (10 mL, 0.05 M)	rt	10	78	87
5	CH_2Cl_2 (20 mL, 0.025 M)	rt	18	78	87
6	CH_2Cl_2 (1 mL, 0.5 M)	0	3	88	56
7	CH_2Cl_2 (1 mL, 0.5 M)	-20	9	85	51

[a] Reactions were carried out with **9** (0.5 mmol), benzene thiol (0.6 mmol) and catalysts **3a** (10 mol%, 0.05 mmol) in CH_2Cl_2. [b] Isolated yields after chromatographic purification. [c] Ee value of **10** was determined by HPLC.

HPLC spectra for Table S7.

The ee value was determined by the HPLC analysis (Chiralpak AS, Hexanes : IPA (1 : 1), 1 mL/min, UV detection at 220 nm, t(major) = 6.09 min, t(minor) = 15.36 min).

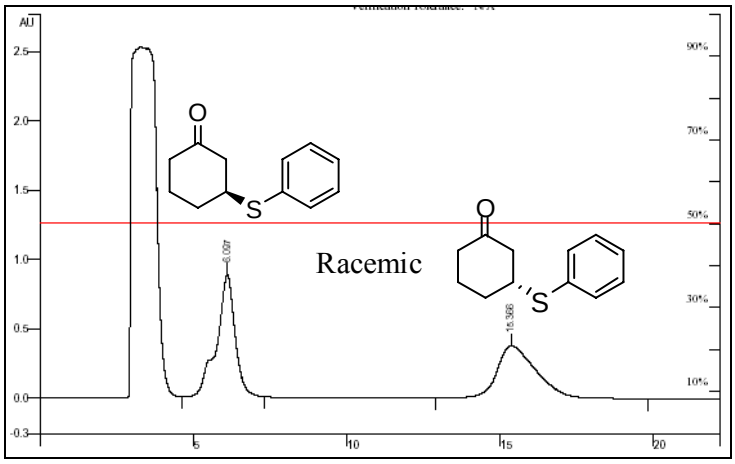
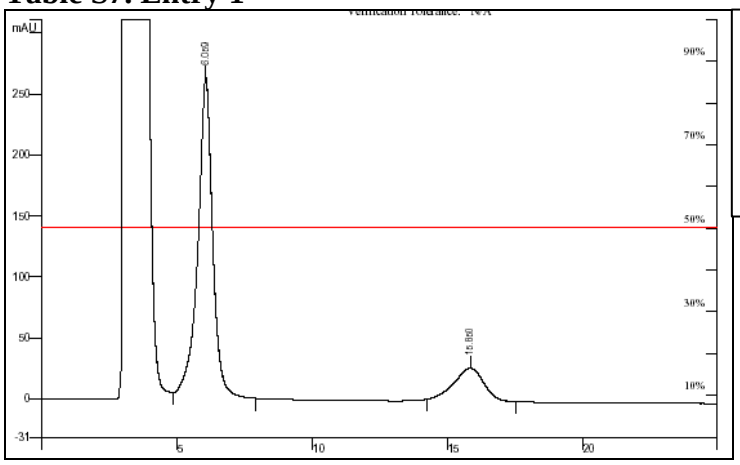
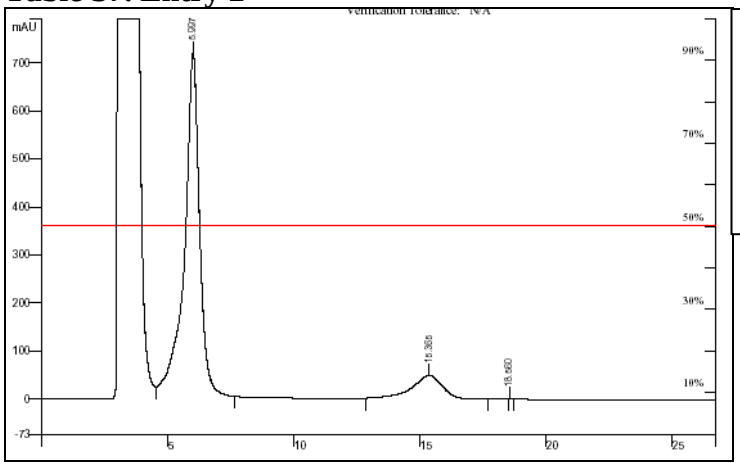


Table S7. Entry 1



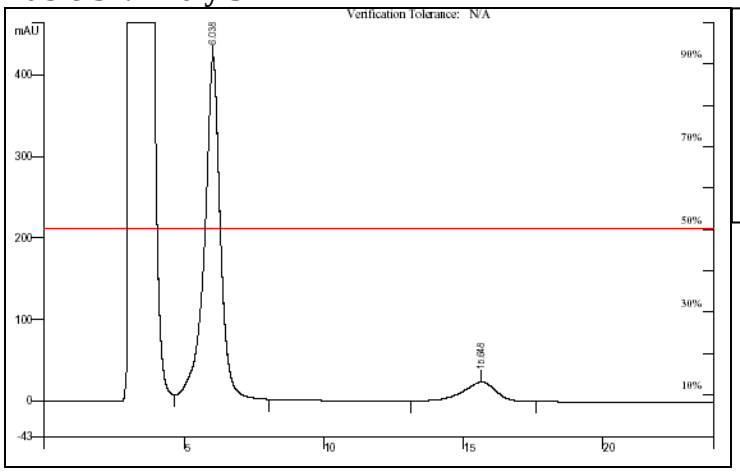
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	82.8964	6.059	97601960	30.8
2	17.1036	15.850	20137786	66.1
	100.0000		117739744	

Table S7. Entry 2



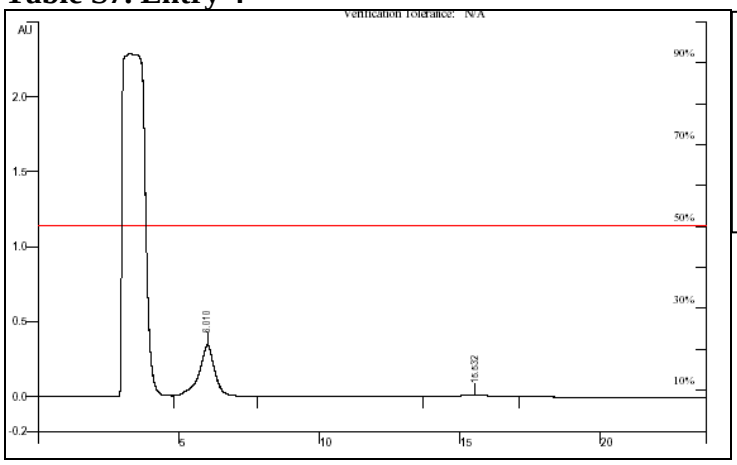
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	87.5151	5.997	281221600	31.0
2	12.4845	15.365	40117712	68.1
3	0.0004	18.560	1406	3.6
	100.0000		321340736	

Table S7. Entry 3



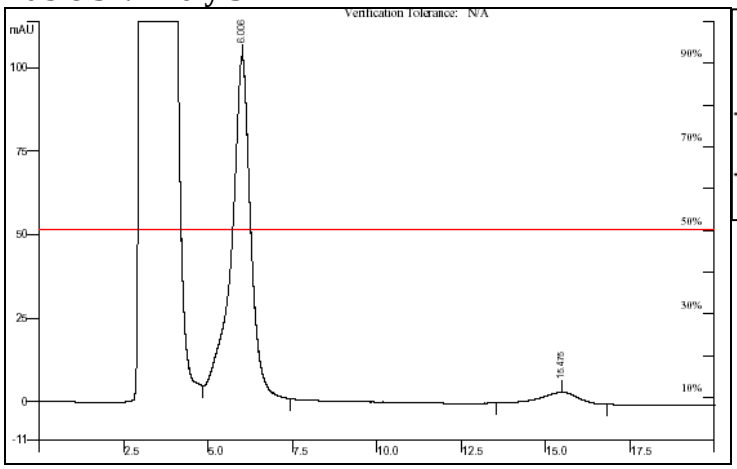
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	89.2935	6.038	161039568	31.4
2	10.7065	15.648	19309038	69.3
	100.0000		180348608	

Table S7. Entry 4



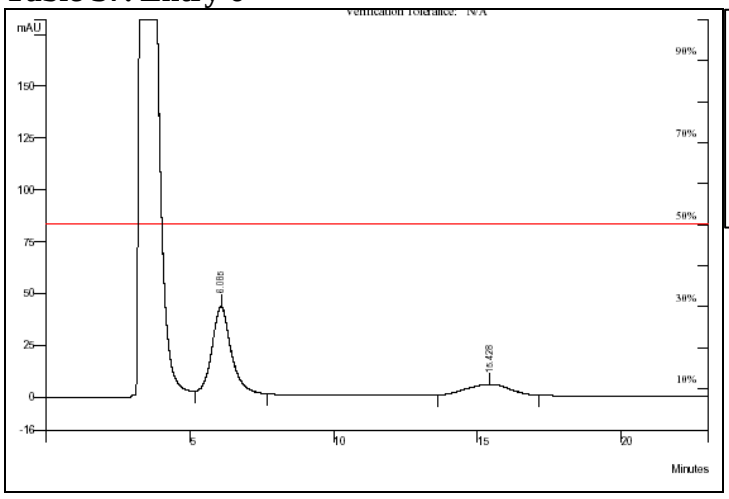
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	93.6221	6.010	129926328	30.8
2	6.3779	15.532	8851057	64.7
	100.0000		138777392	

Table S7. Entry 5



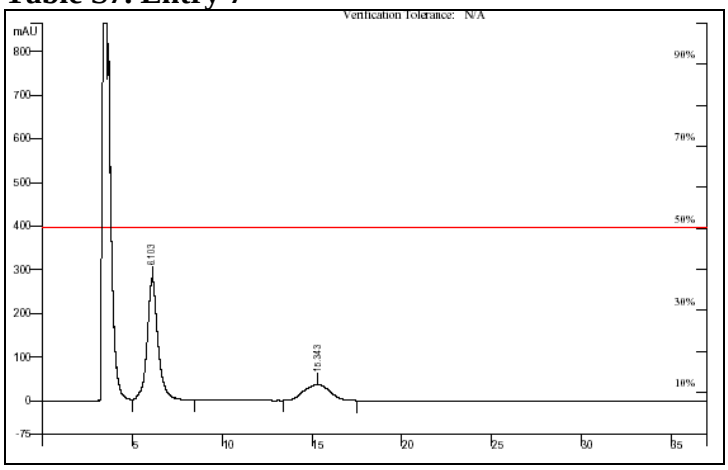
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	93.5760	6.006	38017184	30.0
2	6.4240	15.475	2609886	63.2
	100.0000		40627072	

Table S7. Entry 6



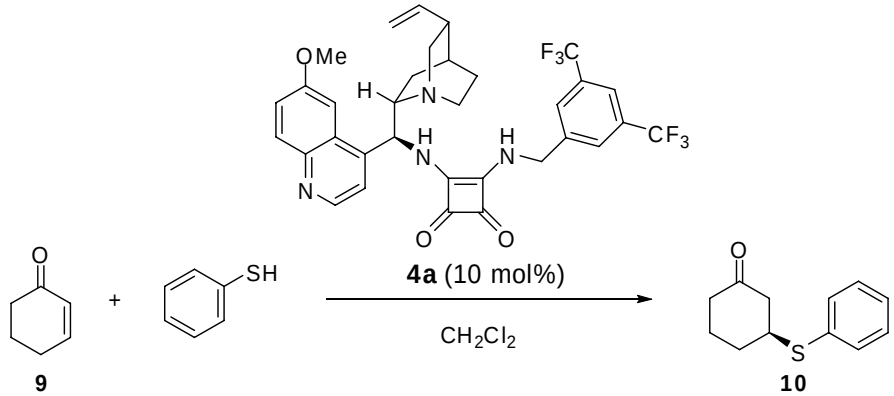
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	78.0949	6.085	18655146	40.8
2	21.9051	15.428	5232650	93.7
	100.0000		23887796	

Table S7. Entry 7



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	75.8770	6.103	115716344	36.0
2	24.1230	15.343	36788896	92.6
	100.0000		**152505248**	

Table S8. Concentration and temperature effect on enantioselectivity in the conjugate addition of benzene thiol to **9** using the catalyst **4a** (Figure 4)



9 **10**

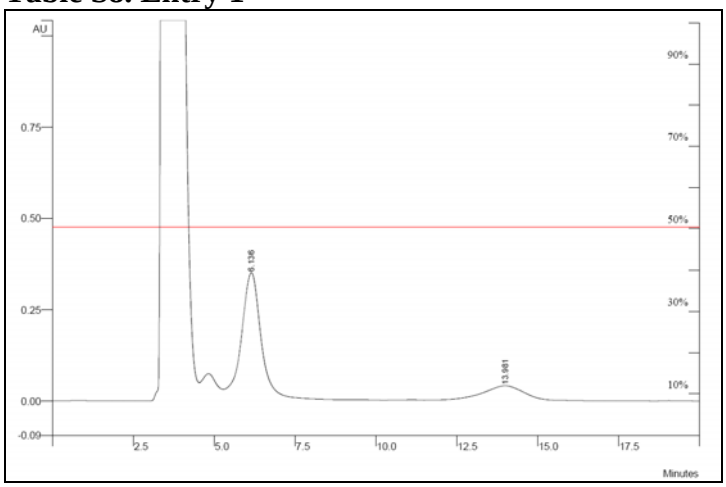
Entry	Concentration	T (^{o}C)	Time (h)	Yield (%)[b]	% ee[c]
1	CH_2Cl_2 (5 mL, 0.1 M)	rt	5	82	60
2	CH_2Cl_2 (10 mL, 0.05 M)	rt	8	81	68
3	CH_2Cl_2 (20 mL, 0.025 M)	rt	16	80	69

[a] Reactions were carried out with **9** (0.5 mmol), benzene thiol (0.6 mmol) and catalysts **4a** (10 mol%, 0.05 mmol) in CH_2Cl_2. [b] Isolated yields after chromatographic purification. [c] Ee value of **10** was determined by HPLC.

HPLC spectra for Table S8.

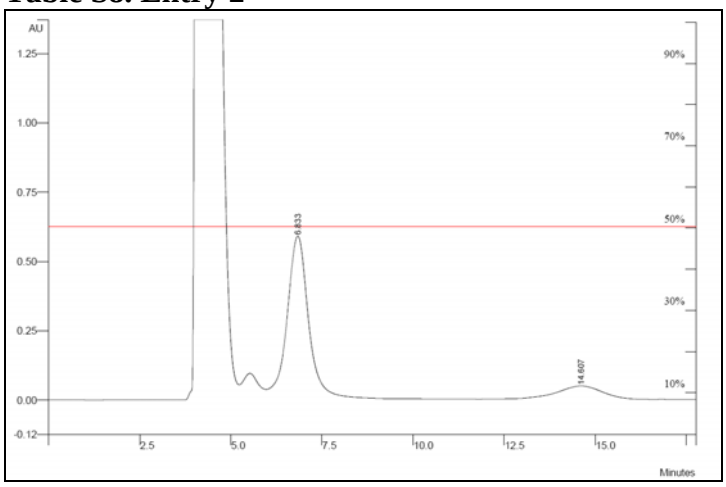
The ee value was determined by the HPLC analysis (Chiralpak AS, Hexanes : IPA (1 : 1), 1 mL/min, UV detection at 220 nm, t(major) = 6.09 min, t(minor) = 15.36 min).

Table S8. Entry 1



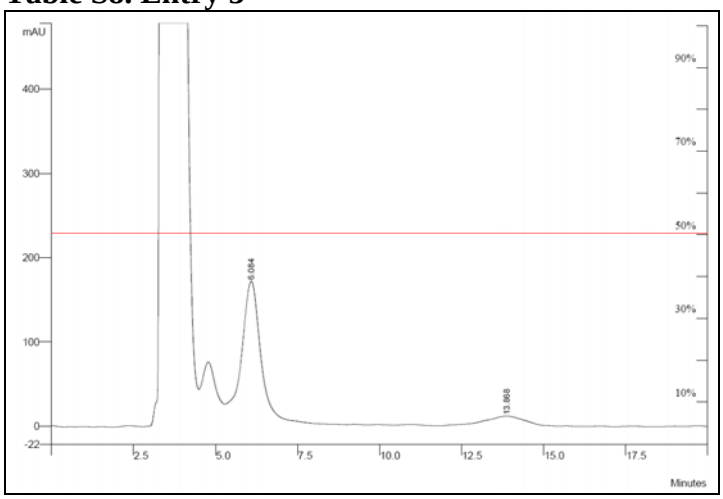
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	80.4444	6.136	125487144	33.8
2	19.5556	13.981	30505194	73.1
	100.0000		**155992336**	

Table S8. Entry 2



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	84.0635	6.833	211715664	33.6
2	15.9365	14.607	40136268	75.1
	100.0000		**251851936**	

Table S8. Entry 3



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	84.3208	6.084	53895040	30.5
2	15.6792	13.868	10021584	75.3
	100.0000		**63916624**	

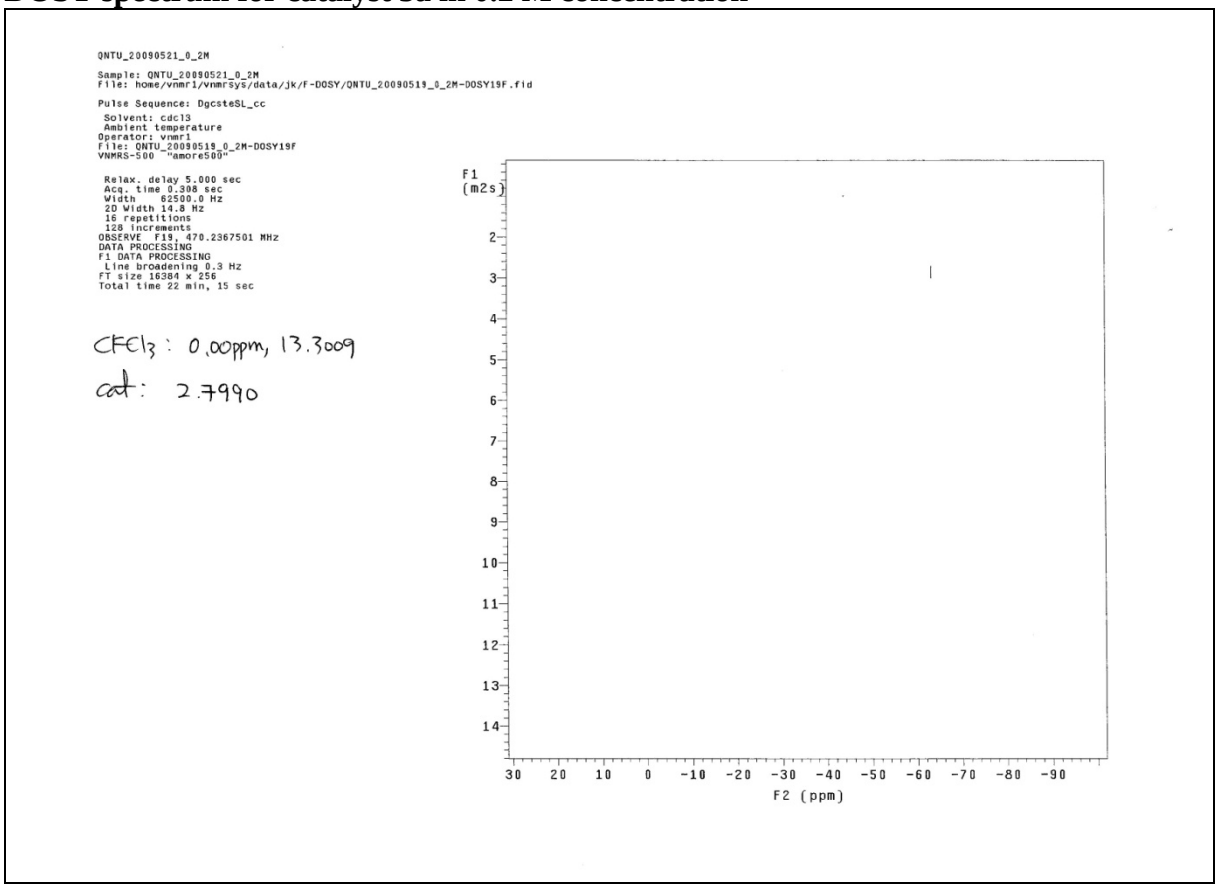
8. DOSY data for Table 1

The ^{19}F DOSY experiment was conducted by using a stimulated echo sequence with self-compensating gradient schemes (convection corrected), a spectral width of 62980 Hz. d1 value was 5s and diffusion gradient length was 3ms and diffusion delay was 50.0 ms. (1000 - 25000, 16 gradient). The baselines of all of the spectra were corrected prior to data processing. The data were processed after the Fourier transformation of each FID with VNMRJ to obtain the chemical shift as the x-axis along with the calculated diffusion coefficient as the y-axis. All of the diffusion coefficient values, *D*, were corrected based on the *D* value of $CFCl_3$ (0.1%, v/v) as an internal standard.

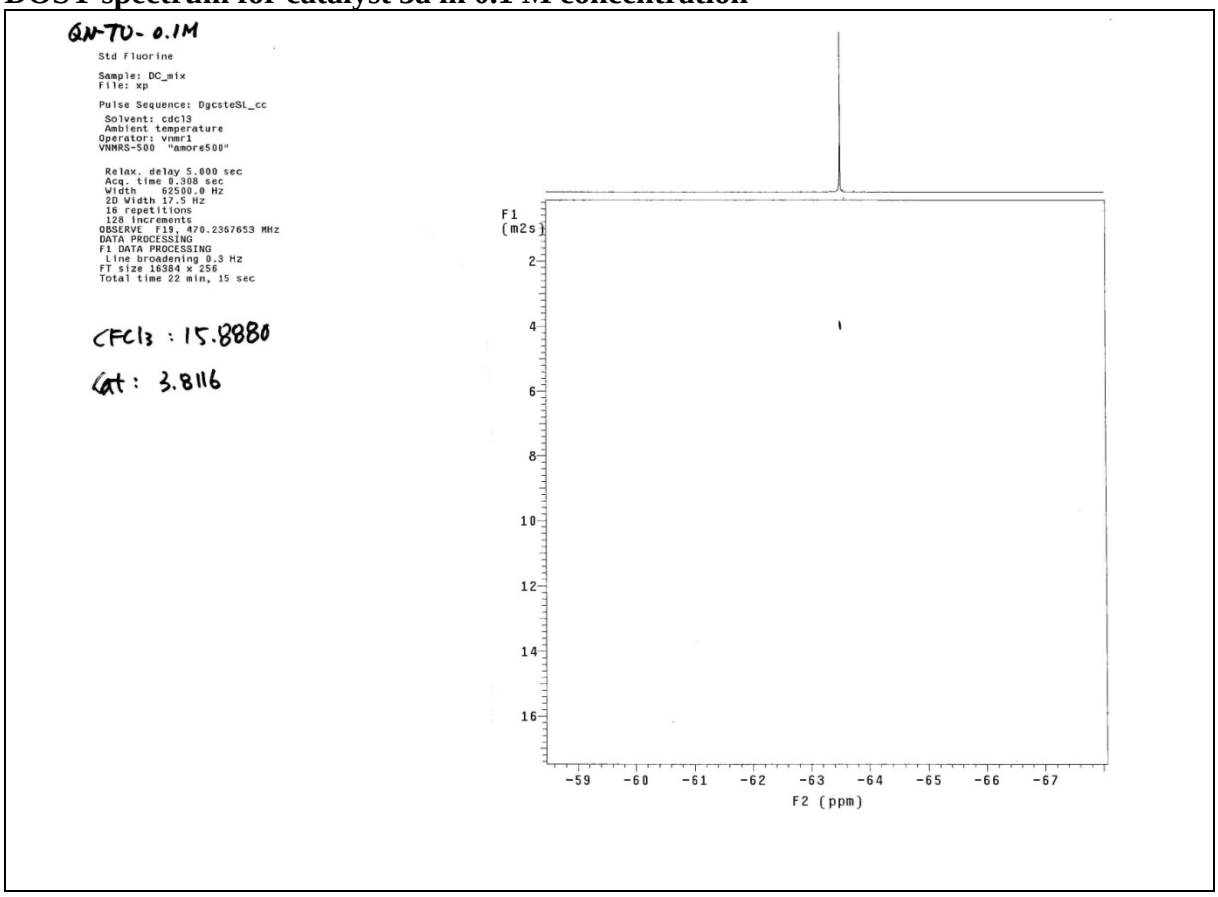
Table S9. Diffusion coefficient of **3a** at different concentration (Table 1)

M ($CDCl_3$)	Relative mol% of catalyst (mol%)	*D* (10^{-10} ms^{-1})		
		$CFCl_3$	**I**	**I** corrected
0.2	100	13.3009	2.7990	3.97
0.1	50	15.8880	3.8116	4.52
0.02	10	16.7638	4.8645	5.47
0.01	5	17.1697	5.1184	5.62
0.002	1	17.997	5.582	5.85
0.001	0.5	18.8613	5.8654	

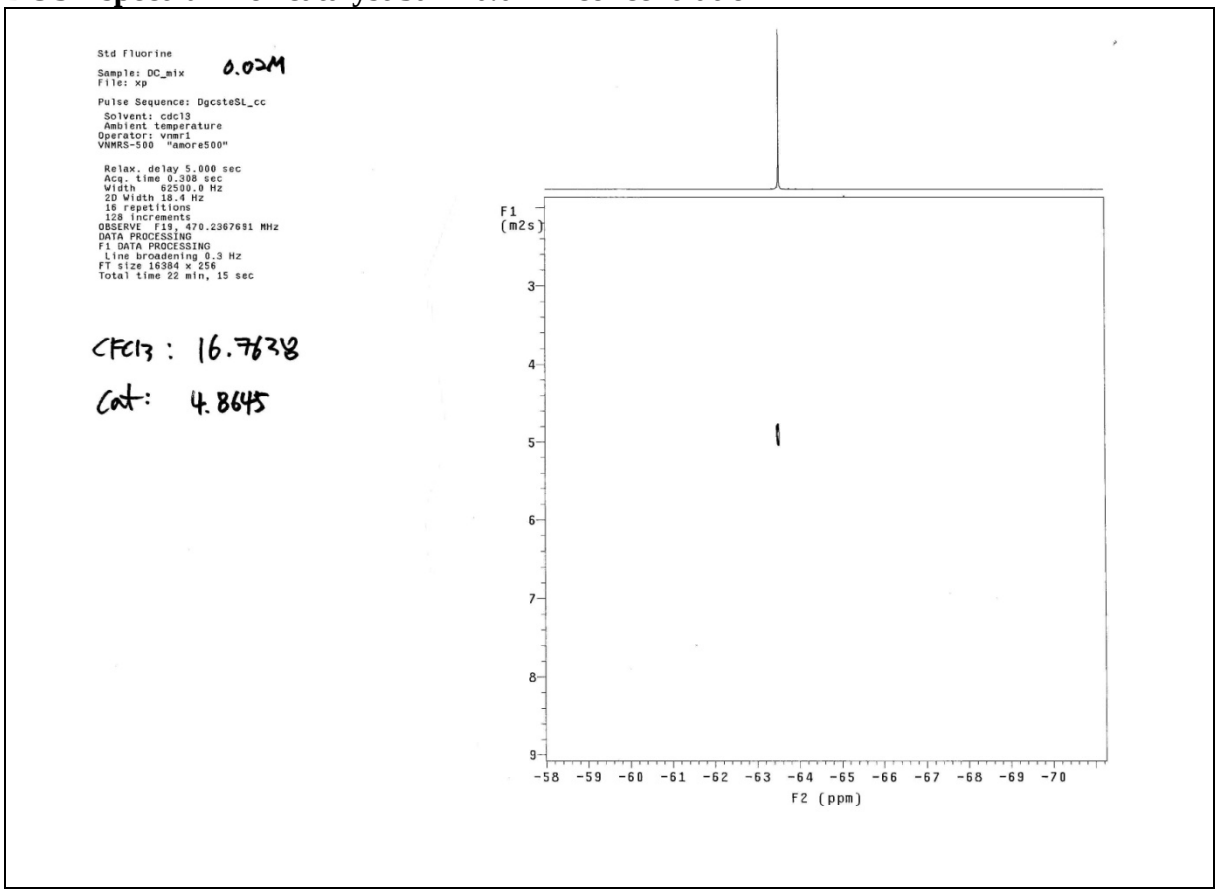
DOSY spectrum for catalyst 3a in 0.2 M concentration



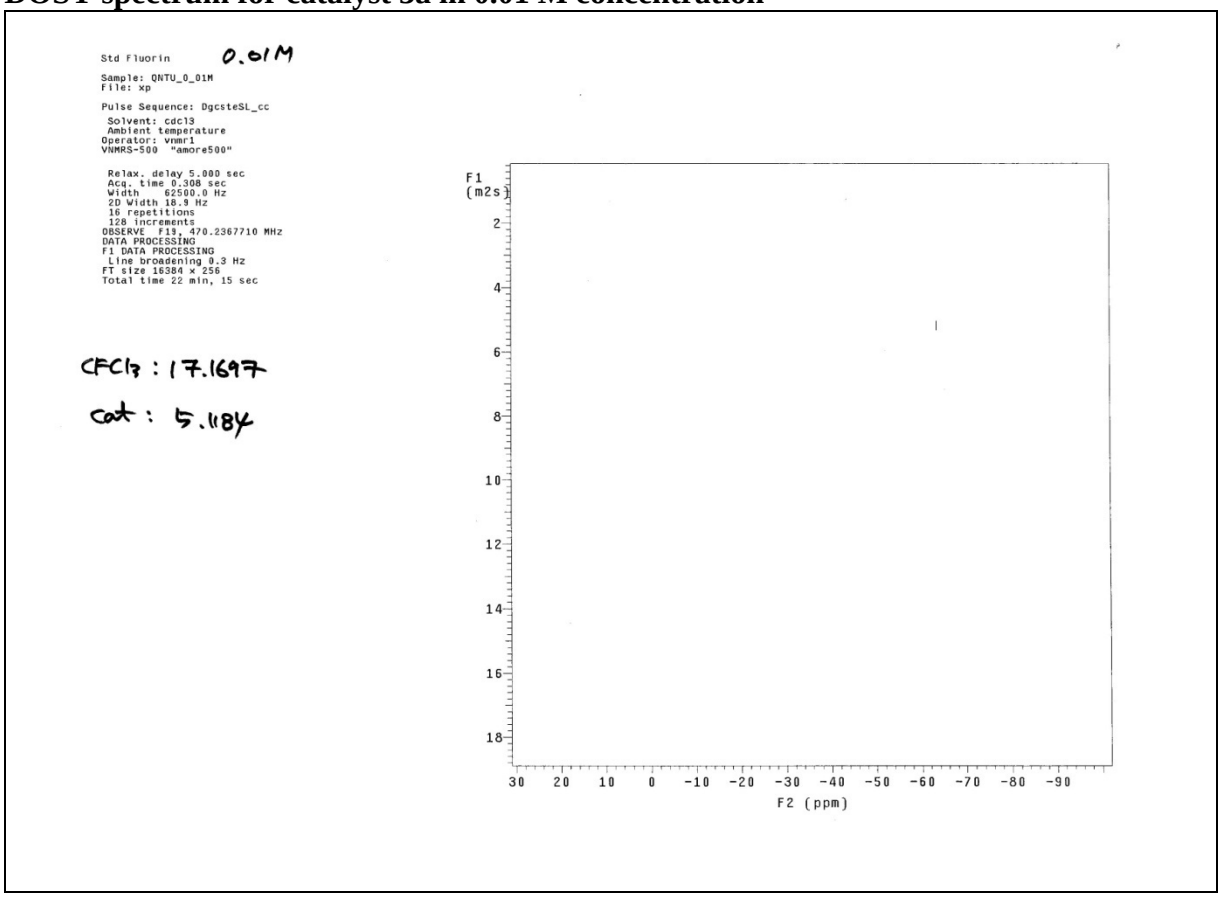
DOSY spectrum for catalyst 3a in 0.1 M concentration



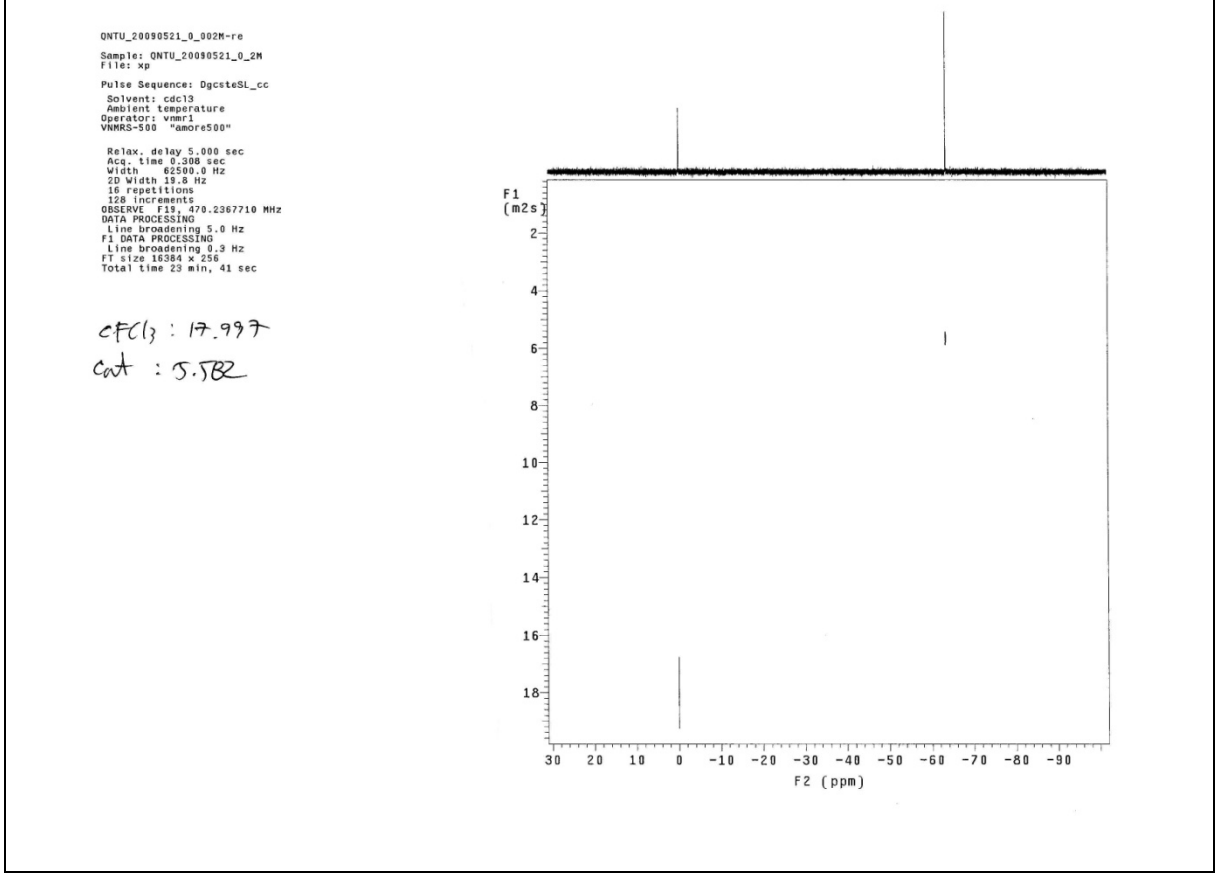
DOSY spectrum for catalyst 3a in 0.02 M concentration



DOSY spectrum for catalyst 3a in 0.01 M concentration



DOSY spectrum for catalyst 3a in 0.002 M concentration



DOSY spectrum for catalyst 3a in 0.001 M concentration

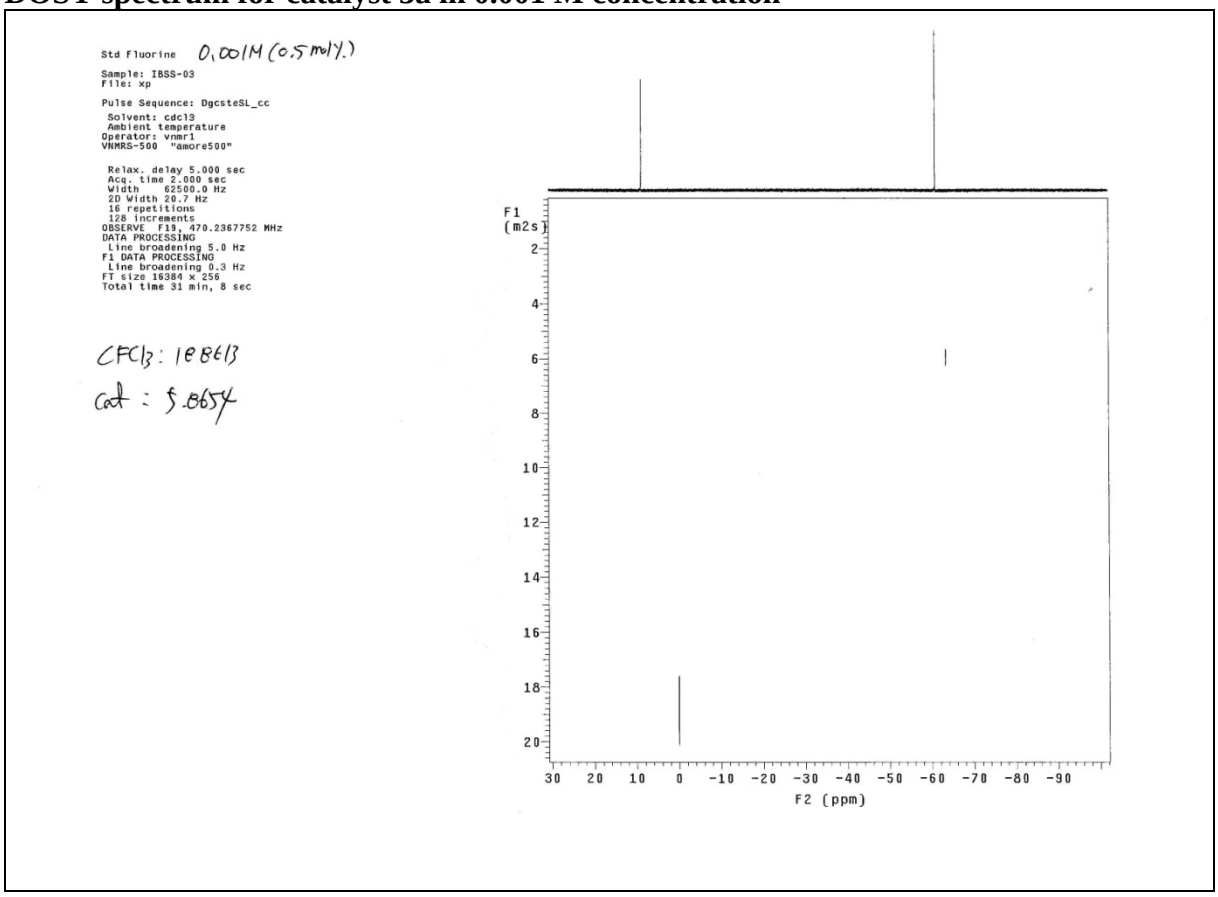
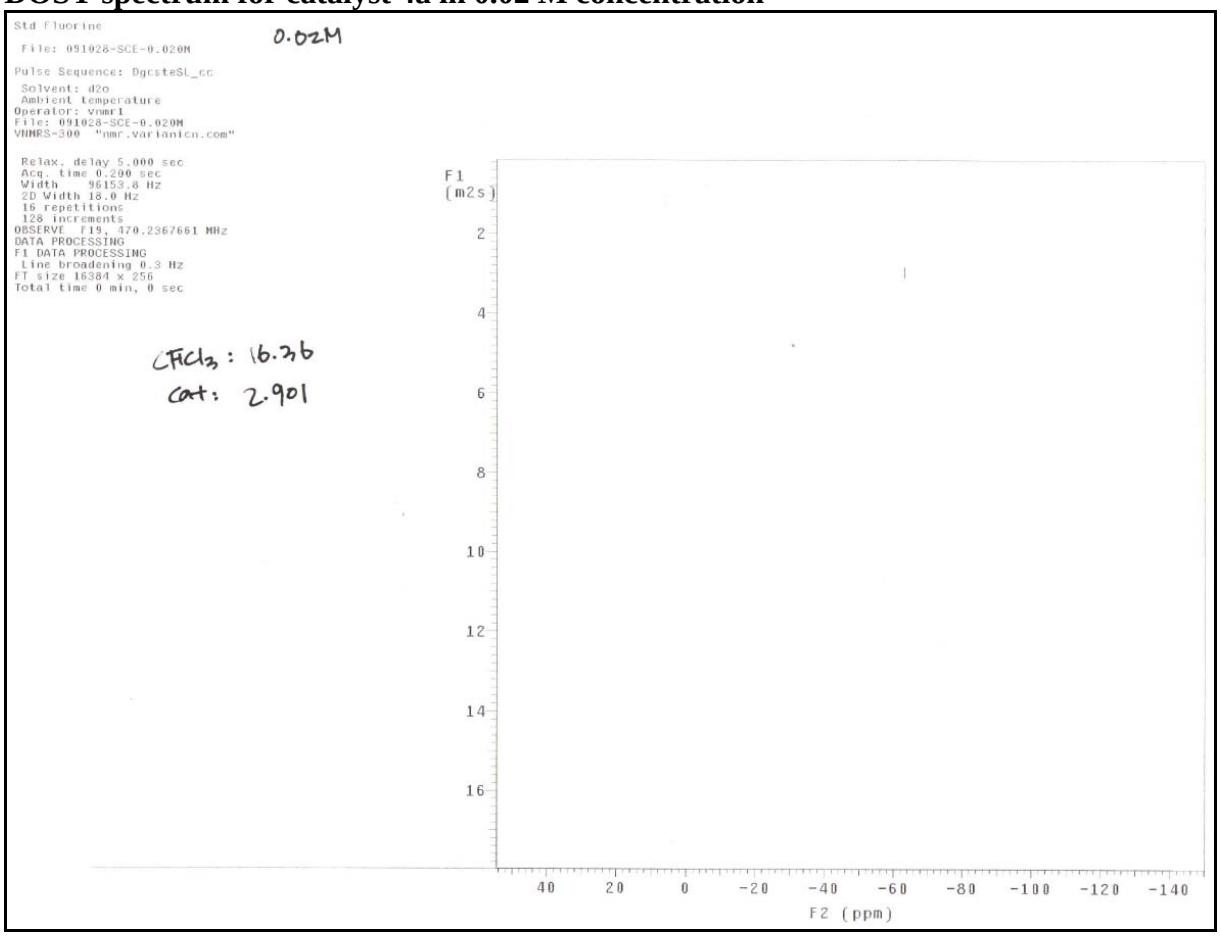


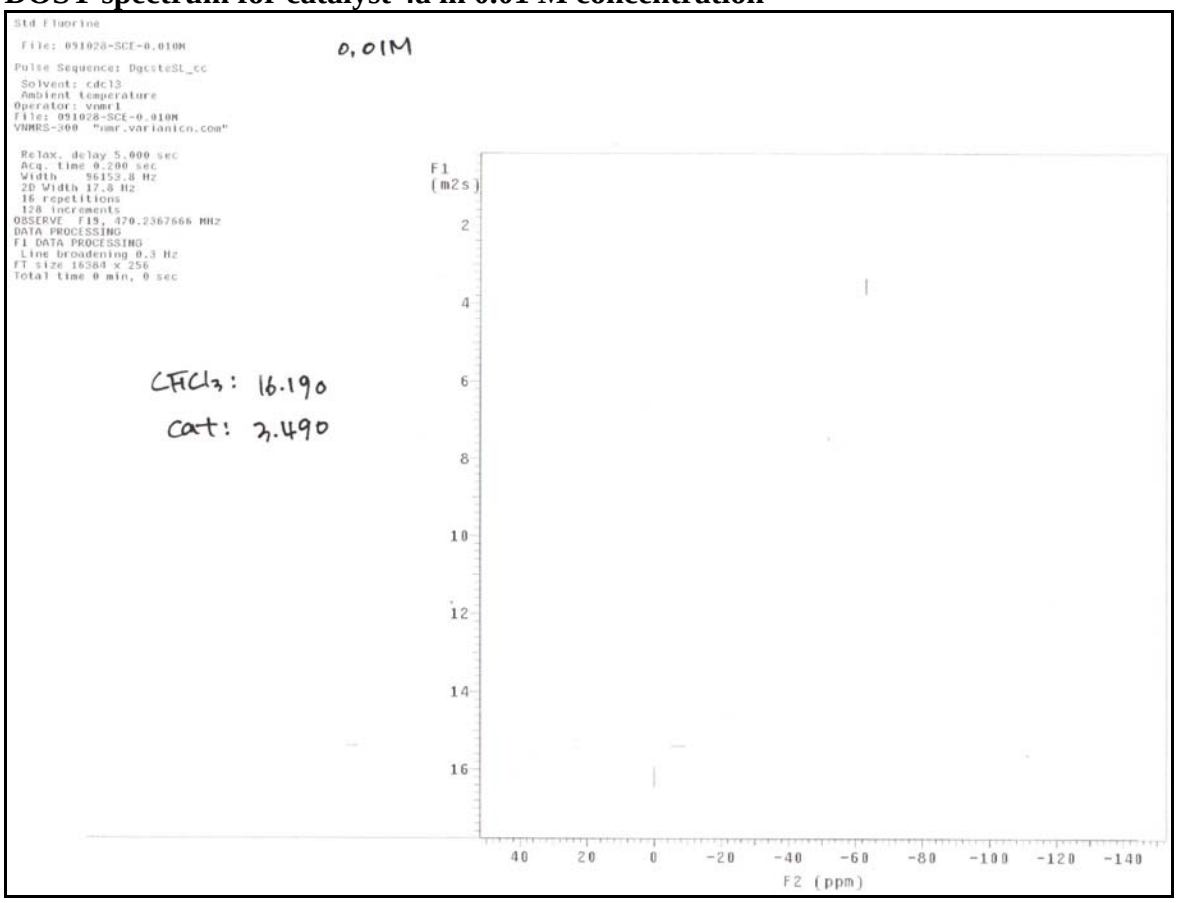
Table S10. Diffusion coefficient of **4a** at different concentration (Table 1)

M (CDCl3)	Relative mol% of catalyst (mol%)	D (10^{-10} ms^{-1})		
		$CFCl_3$	**I**	**I** corrected
0.020	10	16.36	2.901	3.04
0.010	5	16.19	3.490	3.69
0.002	1	16.991	4.718	4.82
0.001	0.5	17.139	4.856	4.85

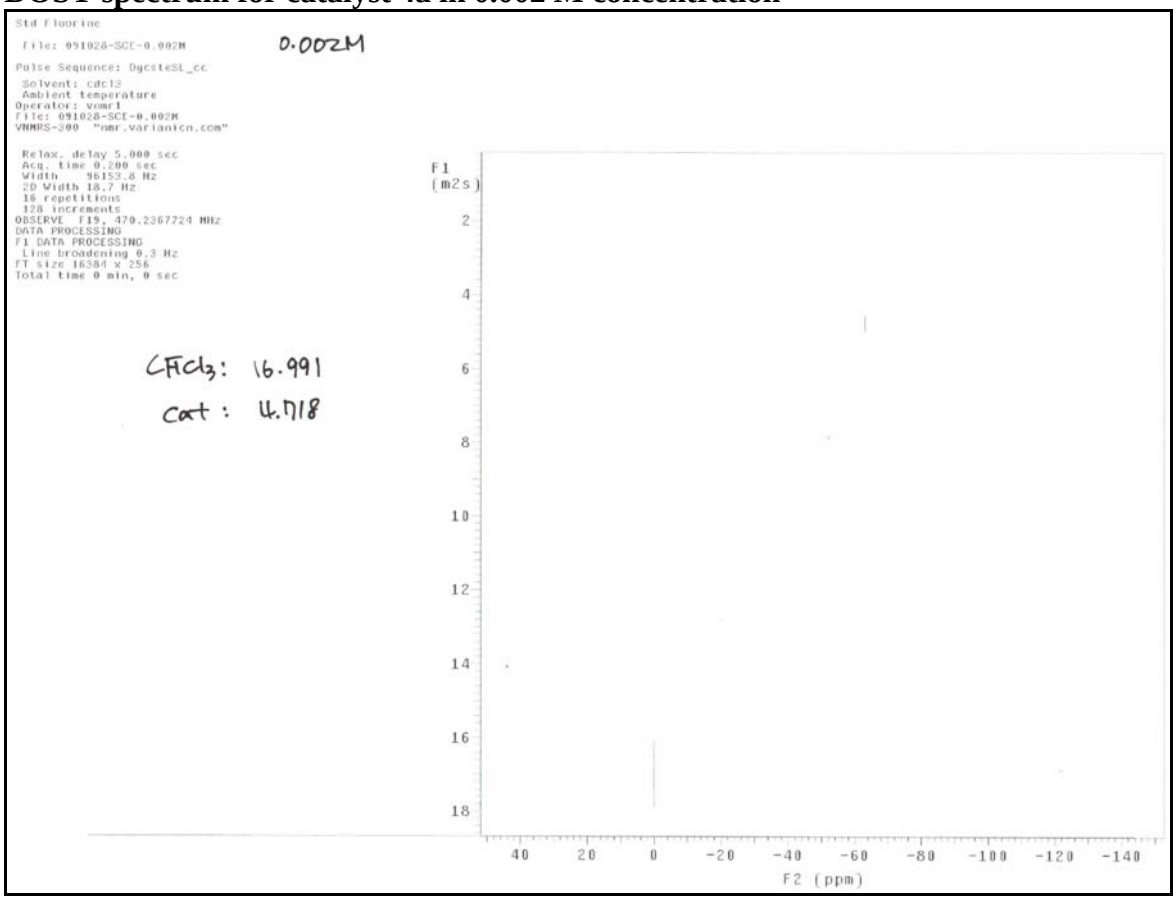
DOSY spectrum for catalyst 4a in 0.02 M concentration



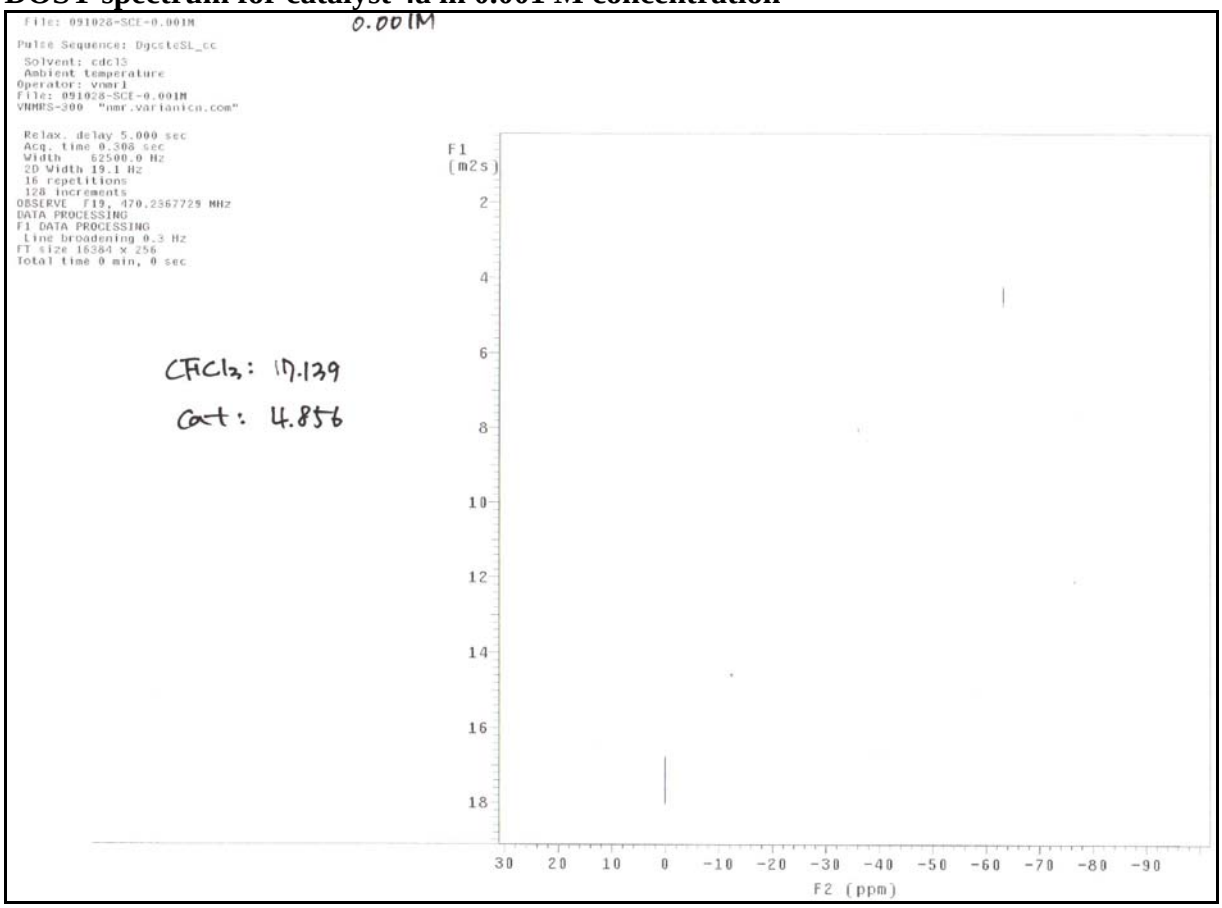
DOSY spectrum for catalyst 4a in 0.01 M concentration



DOSY spectrum for catalyst 4a in 0.002 M concentration

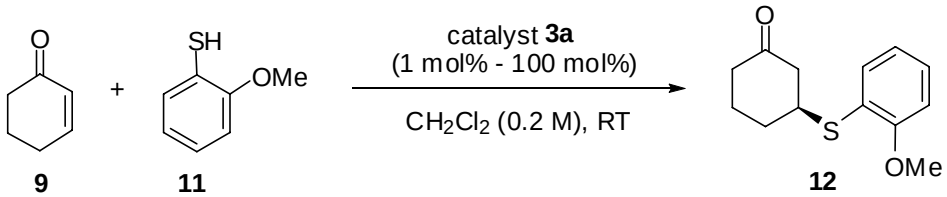


DOSY spectrum for catalyst 4a in 0.001 M concentration



9. HPLC spectra for Table 1.

Table S11. Asymmetric conjugate addition of thiol **11** to cyclohexenone **9** (Figure 4)



9 **11** **12**

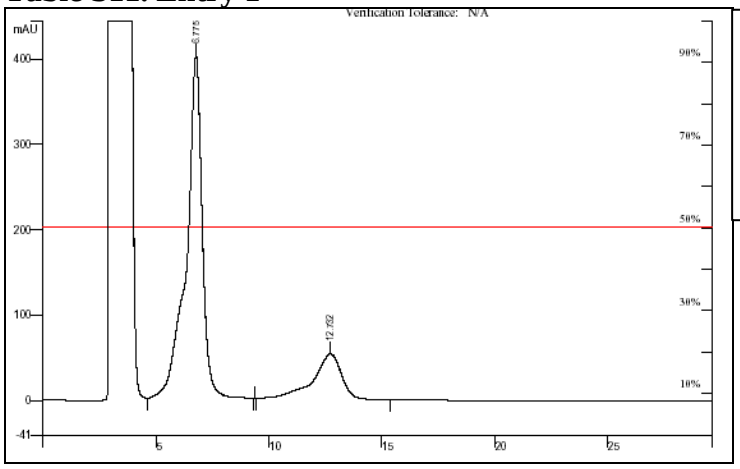
Entry	Catalyst (mol%)	Time (h)	Yield(%)[b]	ee(%)[c]
1	100 mol%	1.5	87	61
2	50 mol%	3	84	71
3	30 mol%	5	88	76
4	20 mol%	8	84	81
5	10 mol%	16	89	86
6	5 mol%	25	85	90
7	2.5 mol%	34	89	92
8	1 mol%	46	87	94

[a] Reactions were carried out on a 0.5 mmol scale in CH_2Cl_2 (2.5 mL) at room temperature.

HPLC spectra for Table S11.

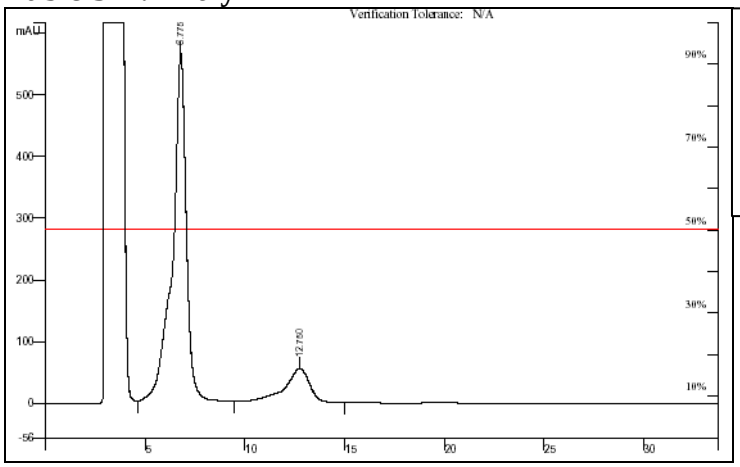
The ee value was determined by the HPLC analysis (Chiralpak AS, Hexanes : IPA (1 : 1), 1 mL/min, UV detection at 220 nm, *t*(major) = 6.75 min, *t*(minor) = 12.73 min).

Table S11. Entry 1



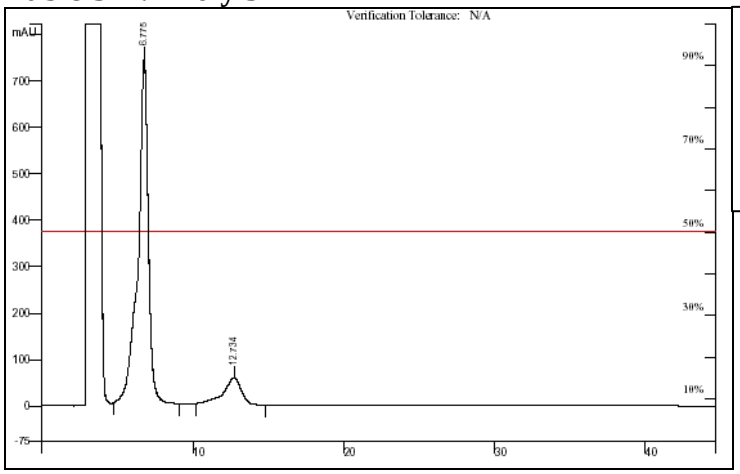
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	80.4285	6.775	197066592	34.7
2	19.5715	12.732	47954380	63.8
	100.0000		245020976	

Table S11. Entry 2



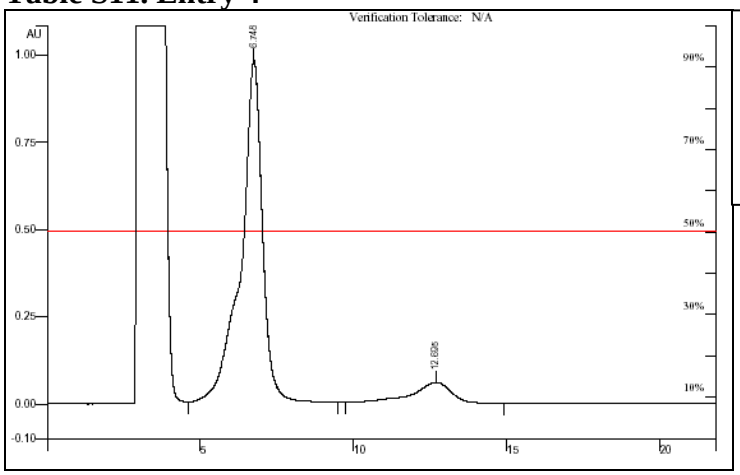
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	85.6164	6.775	275001760	34.5
2	14.3836	12.750	46200544	0.0
	100.0000		321202304	

Table S11. Entry 3



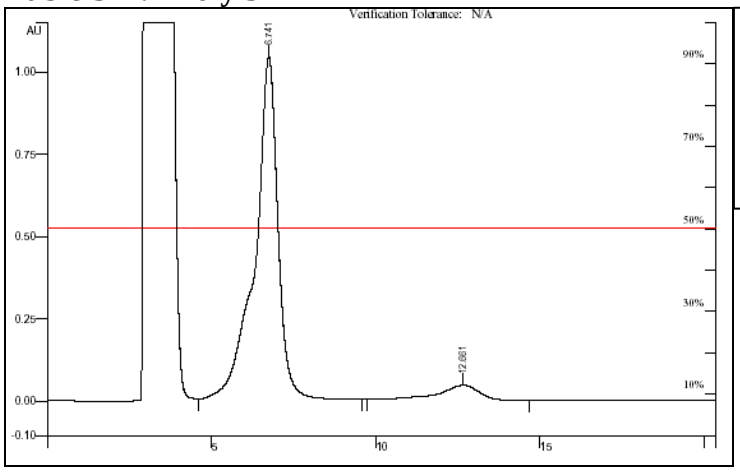
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	88.4073	6.775	352283872	34.3
2	11.5927	12.734	46194176	63.8
	100.0000		398478048	

Table S11. Entry 4



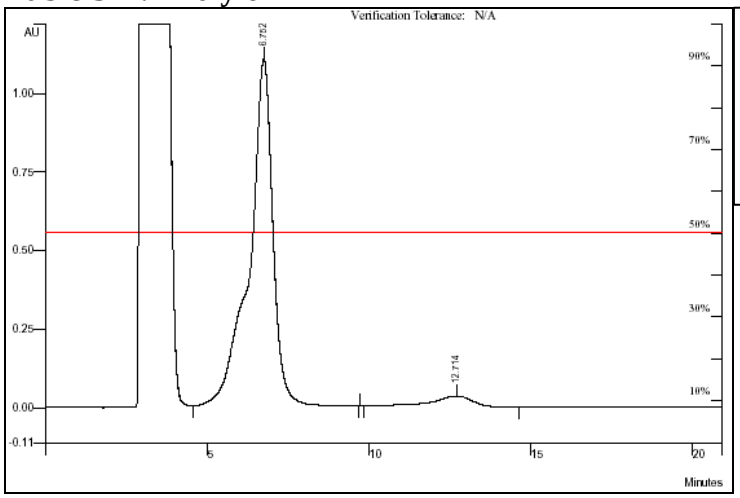
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	90.5120	6.748	475025024	34.8
2	9.4880	12.695	49795004	65.0
	100.0000		**524820032**	

Table S11. Entry 5



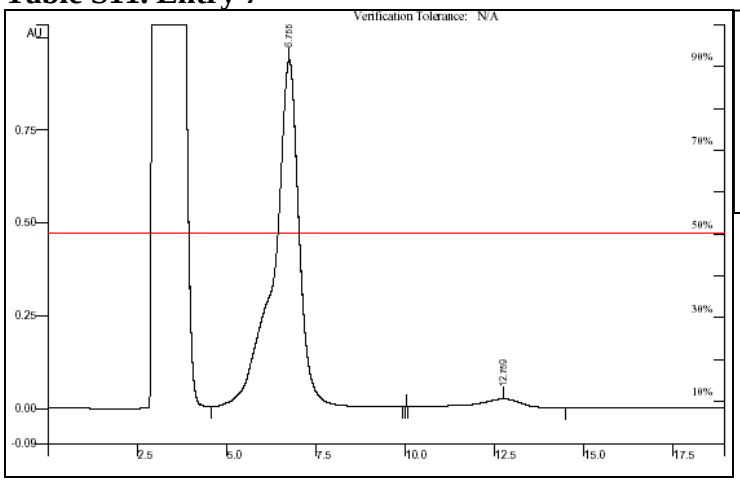
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	93.0930	6.741	504594240	34.9
2	6.9070	12.661	37438180	63.7
	100.0000		**542032448**	

Table S11. Entry 6



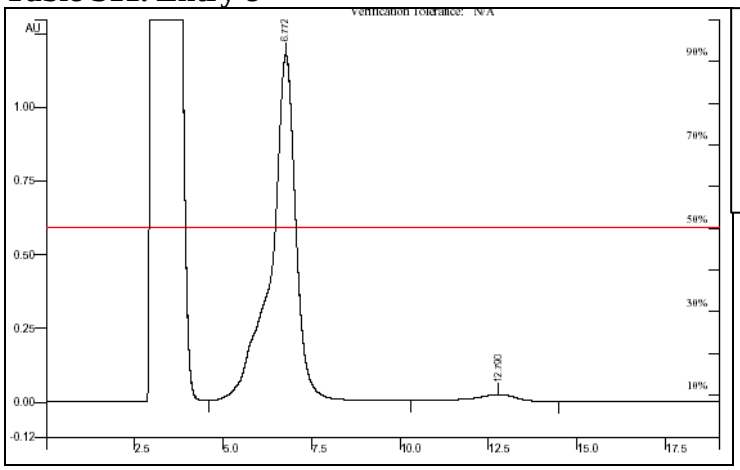
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	95.0741	6.752	561905344	35.6
2	4.9259	12.714	29112804	0.0
	100.0000		**591018176**	

Table S11. Entry 7



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	95.9343	6.755	459922080	34.8
2	4.0657	12.759	19491438	62.5
	100.0000		479413504	

Table S11. Entry 8



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	96.9019	6.772	577135168	34.4
2	3.0981	12.790	18452132	0.0
	100.0000		595587328	

Table S12. Concentration effect on enantioselectivity in the conjugate addition of benzene thiol **11** to **9** using the catalyst **4a** (Table 1)[a]

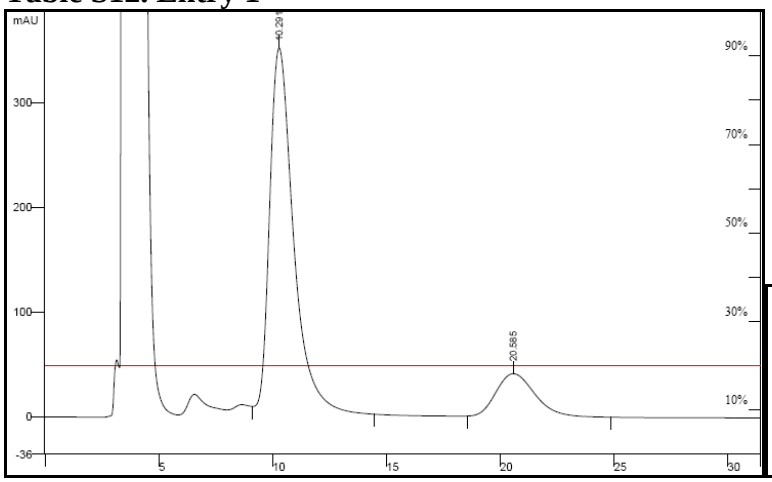
Entry	Catalyst	Time (h)	Yield (%)	% ee
1	(10 mol%)	2	89	67.2
2	(5 mol%)	4	87	79.2
3	(2 mol%)	11	82	84.4
3	(1 mol%)	17	85	90.1
4	(0.5 mol%)	31	87	91.3
5	(0.25 mol%)	46	80	92.7

[a] Reactions were carried out at 0.5 mmol scale in 2.5 mL CH_2Cl_2 in room temperature at various catalyst concentrations

HPLC spectra for Table S12.

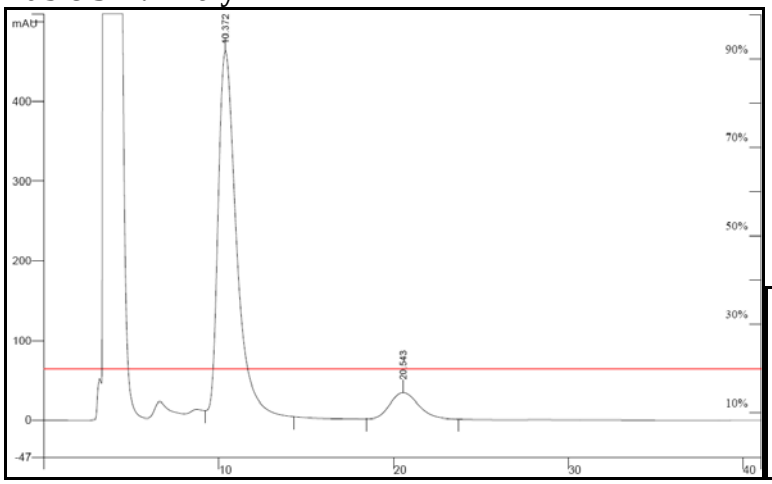
The ee value was determined by the HPLC analysis (Chiralpak AS, Hexanes : IPA (8 : 2), 1 mL/min, UV detection at 220 nm, t(major) = 10.3 min, t(minor) = 20.5 min).

Table S12. Entry 1



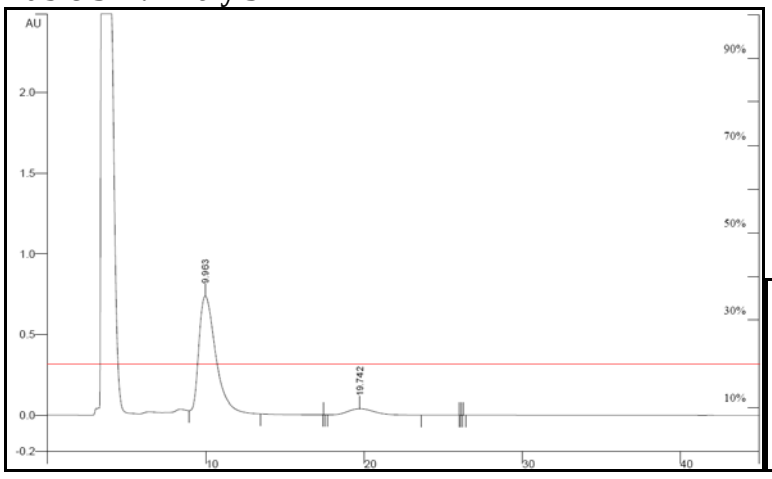
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	83.5849	10.291	244508864	68.3
2	16.4151	20.585	48018600	112.6
	100.0000		**292527456**	

Table S12. Entry 2



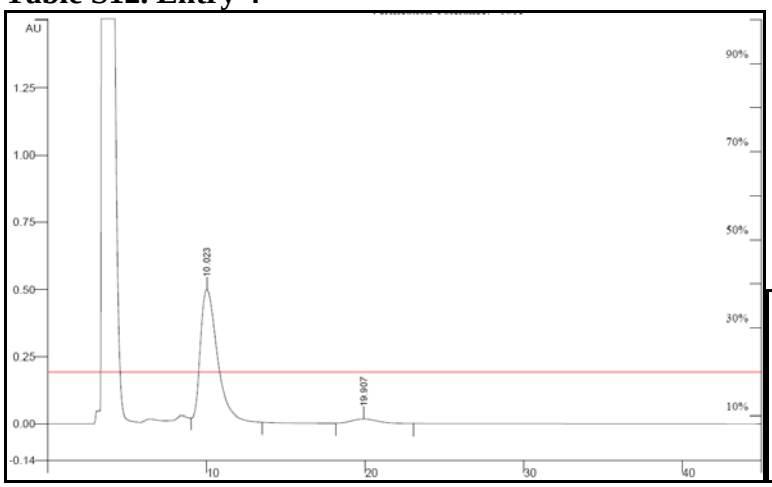
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	89.6040	10.372	322829696	68.7
2	10.3960	20.543	37455344	107.8
	100.0000		**360285056**	

Table S12. Entry 3



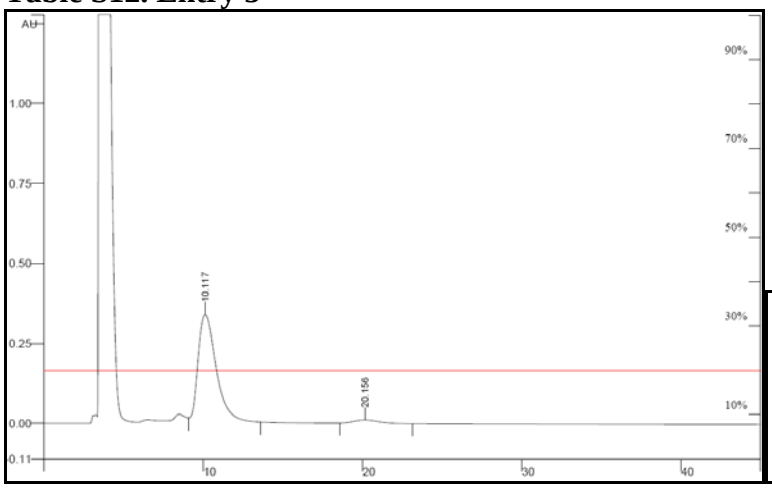
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	92.1674	9.963	515379008	71.7
2	7.8326	19.742	43798116	109.3
	100.0000		**559177152**	

Table S12. Entry 4



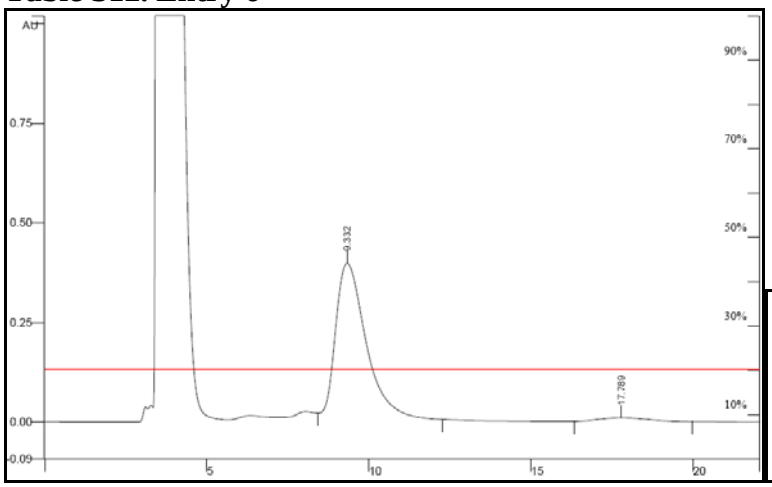
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	95.0407	10.023	347940032	71.6
2	4.9593	19.907	18155770	106.8
	100.0000		**366095808**	

Table S12. Entry 5



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	95.6631	10.117	248527968	76.1
2	4.3369	20.156	11266954	99.6
	100.0000		**259794928**	

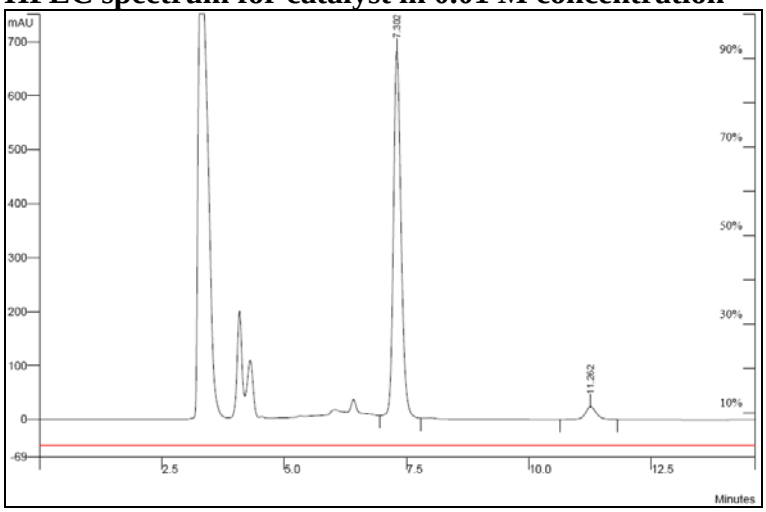
Table S12. Entry 6



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	96.3943	9.332	240561504	61.4
2	3.6057	17.789	8998429	93.5
	100.0000		**249559936**	

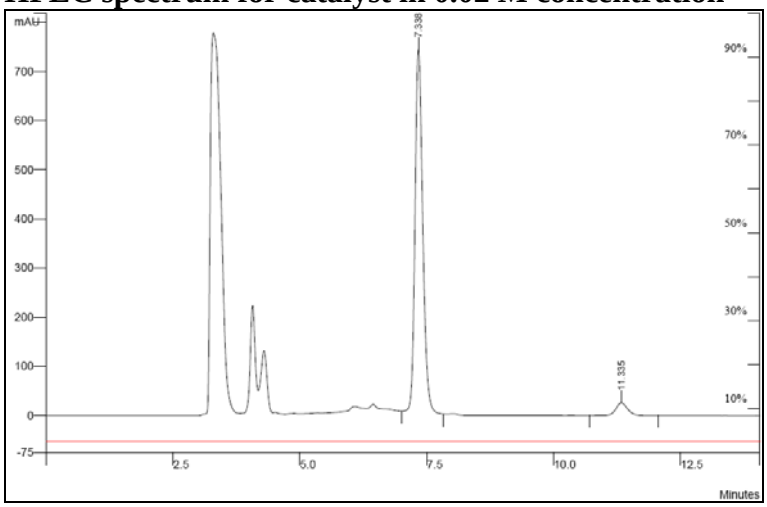
10. HPLC spectra for Figure 6

HPLC spectrum for catalyst in 0.01 M concentration



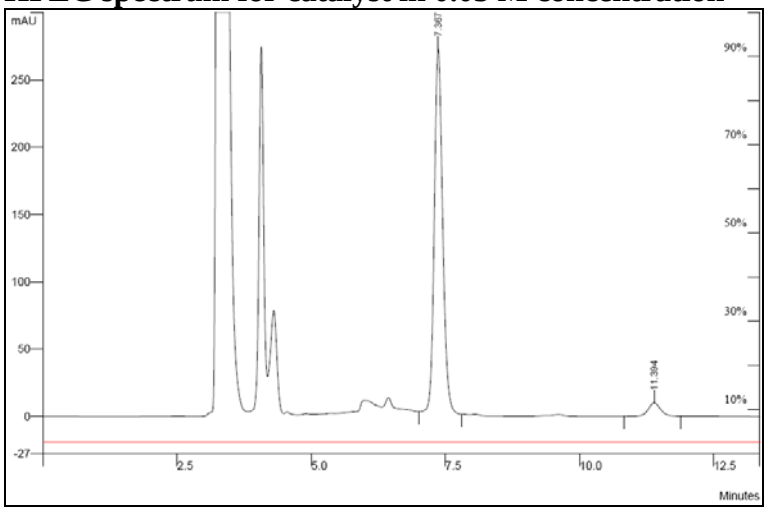
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	95.2949	7.302	72714280	9.7
2	4.7051	11.262	3590216	13.8
	100.0000		**76304496**	

HPLC spectrum for catalyst in 0.02 M concentration



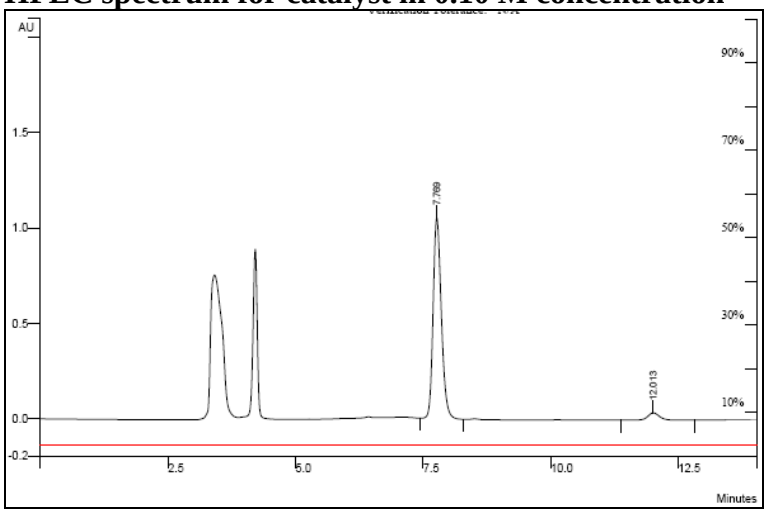
Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	95.1139	7.338	77977920	9.6
2	4.8861	11.335	4005835	14.2
	100.0000		**81983752**	

HPLC spectrum for catalyst in 0.05 M concentration



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	95.0046	7.367	29307148	9.8
2	4.9954	11.394	1540986	14.2
	100.0000		**30848134**	

HPLC spectrum for catalyst in 0.10 M concentration



Peak No	Result ()	Ret. Time (min)	Area (counts)	Width 1/2 (sec)
1	95.2126	7.769	117865112	10.2
2	4.7874	12.013	5926434	14.1
	100.0000		123791544	

11. References

[1] J. Liang, J. C. Ruble, G. C. Fu, *J. Org. Chem*. **1998**, *63*, 3154-3155.
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[5] Y. Chen, S-. K. Tian, L. Deng *J. Am. Chem. Soc.* **2000**, *122*, 9542-9543.
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