·基础学科·

C_2 -轴对称联苯类手性双膦配体的研究进展(二)

马梦林[1,2],张园园[1,2],杨 静[1],李伟[1,4],胡高波[1,3],付海燕[2],陈 华[2]

(1. 西华大学物理与化学学院,四川 成都 610039; 2. 教育部绿色化学重点实验室,四川大学化学学院有机金属络合催化研究所,四川 成都 610064; 3. 厦门大学化学化工学院,福建 厦门 361005; 4. 贵州大学生命科学学院,贵州 贵阳 550025)

摘 要: 手性膦配体的合成及其在手性诱导催化反应中的应用一直是不对称合成与催化研究中非常重要的研究领域之一。近十年来,大量的 C_2 -轴对称手性双膦配体被合成出来并成功地应用于不对称催化研究,本文从 C_2 -轴对称联苯类手性双膦配体的介绍、合成方法、C_2 -轴对称联苯类手性双膦配体在不对称催化氢化以及其在其他不对称诱导反应中的应用4个方面综述了相关研究进展。

关键词: 联苯; C_2 -轴对称; 手性双膦配体; 不对称; 催化

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Progress of C_2 -Symmetric Biphenyl Bisphosphine Ligands Ⅱ

MA Meng-lin[1,2], ZHANG Yuan-yuan[1,2], YANG Jing[1], LI Wei[1,4],
HU Gao-bo[1,3], FU Hai-yan[1], CHEN Hua[2]

(1. *School of Physics and Chemistry, Xihua University, Chengdu* 610039 *China*;
2. *Key lab of Green Chemistry and Technology of Ministry of Education, The Institute of Homogeneous Catalysis, Faculty of Chemistry, Sichuan University, Chengdu* 610064 *China*; 3. *Department of Chemistry and Key Laboratory for Chemical Biology of Fujian Province, College of Chemistry and Chemical Engineering, Xiamen University, Xiamen* 361005 *China*;
4. *College of Life Science, Guizhou University, Guiyang* 550025 *China*)

Abstract: A vast number of biphenyl atropisomeric diphosphine ligands have been successfully applied in asymmetric catalysis. The synthesis and applications of this type of ligands are a continuous interesting theme in organic chemistry. This review describes recent progress in synthesis and application of C_2 -Symmetric diphosphine ligands on the asymmetric catalysis hydrogenation and other asymmetric induced reaction.

Key words: C_2 -symmetric biphenyl; atropisomeric chiral; diphosphine ligand; catalysis

3 C_2 -轴对称联苯类双膦配体在不对称催化氢化反应中的应用

3.1 不对称催化氢化脱氢氨基酸

α-脱氢氨基酸衍生物的不对称催化氢化是发展得最早的不对称催化反应,人们对它的研究也较深入,(*Z*)-2-乙酰胺基肉桂酸及酯成为评价配体性能的标准底物之一。Noyori 等[1]的 BINAP 在催化氢化 α-脱氢氨基酸反应中获得了 99% 以上的 *e. e.* 值,随后多种 C_2 -轴对称联苯类手性双膦配体相继被用于 α-脱氢氨基酸衍生物的不对称催化氢化研究,如表1所示。

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作者简介: 马梦林(1975-),男,副教授,博士,主要研究方向为有机合成、生物有机化学。

表 1 C_2 – 轴对称手性双膦配体催化 α – 脱氢氨基酸氢化反应

Catalyst	Sub.	Reaction Condition	yield/%	*e. e.* /%	ref
[BINAPRh(OCH3)2]$^+ClO_4^-$	A	EtOH, rt, 3 atm, 48h	96	96	1
[BINAPRh(OCH3)2]$^+ClO_4^-$	B	EtOH, rt, 3 atm, 48h	97	98	1
[BICHEPRh(nbd)]$^+ClO_4^-$	C	THF, rt, 1 atm, 10min	100	99	2
[BICHEPRh(nbd)]$^+ClO_4^-$	D	Toluene, rt, 1atm, 10min	100	99	2
[BICHEPRh(nbd)]$^+Cl^-$	D	EtOH, rt, 5 atm, 10min	100	83	2
(RuMeO – BIPHEP – S($OCOCF_3$)$_2$	E	MeOH, rt, 10atm, 4h	100	75	3
[RhMeO – BIPHEP – S(cod)]$^+BF_4^-$]	F	H_2O, rt, 10atm, 66h	100	66	3
[Rh H_8 – BINAP(cod)]$^+BF_4^-$	G	CH_2Cl_2, 0℃, 3at, 10min	99	96	4
SYNPHOS/ [Ru(cod)(methylallyl)$_2$]	G	MeOH, 50℃, 5atm, 24h	100	86	5
[RhOctoBIPHEMP (cod)$_2$] TOf	G	MeOH, 50℃, 3atm, 15h	100	88	6
[Rh L_{15}(cod)$_2$] TOf	G	MeOH, rt, 3atm, 10min	100	74	6
Rh(nbd)$_2SbF_6$/MeO – BIPHEP	E	CH_2Cl_2, rt, 1.7atm, 24h	100	36	7
Rh(nbd)$_2SbF_6$/o – PhMeOBIPHEP	H	MeOH, rt, 4atm,, 24h	100	99	7
[Rh L_{17} ~ L_{18}(nbd)$_2$] BF_4	G	MeOH, rt, 1atm, 10min	—	45	8
[RhMeO – BIPHEP(nbd)$_2$] BF_4	G	MeOH, rt, 1atm, 10min	—	29	8
[MeO – BIPHEP($RuBr_2$)]	G	EtOH, 50℃, 10atm, 24h	100	68	9
[MeO – NAPhePHOS – ($RuBr_2$)]	G	EtOH, 50℃, 10atm, 24h	100	69	9
[TriMe – NAPhePHOS – ($RuBr_2$)]	G	EtOH, 50℃, 10atm, 24h	100	70	9
[Ru(2 – methylallyl)$_2$(L_{17})]	G	MeOH, rt, 1atm, 10min	—	45	8
[Ru(2 – methylallyl)$_2$(L_{18})]	G	MeOH, rt, 1atm, 10min	—	40	8

注: L_{17} 和 L_{18} 络合物循环 2 次后产物 *e. e.* 值保持不变。

与上述常见的 1, 2 加成不同, α – 脱氢氨基酸可在 C_2 – 轴对称配体 Ru 络合物催化下与三氟化硼酸发生共轭 1, 4 – 加成, 经不对称质子化反应生成相应手性氨基酸[10], 如图 1 所示。

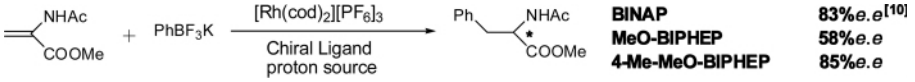

图 1 α – 脱氢氨基酸共轭 1,4 – 加成

与 α – 脱氢氨基酸的氢化相比, β – 脱氢氨基酸高效的催化体系较少见, HexaPHEMP[11] 和 L_7[12] 与金属 Ru 的络合物分别获得了 95% 和 94% ~99% 的 *e. e.* 值。

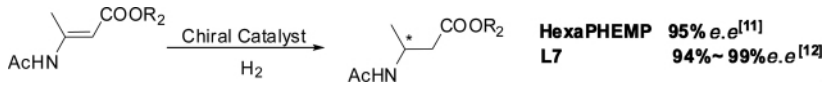

图 2 催化氢化 β – 脱氢氨基酸

2008 年 Bellefoh 等[13] 采用多种配体的 Rh 络合物对脱氢氨基酸进行不对称催化氢化氢气压力对反应的影响研究, 结果显示氢气压力对 *e. e.* 值影响不是孤立的而是与配体密切相关的。

3.2 不对称催化氢化未含官能团芳香酮羰基

未含官能团的芳基烷基酮, 除酮羰基外不具有和催化剂中心金属进行配位的辅助功能基, 通常对钌 – 膦催化剂加氢的对映选择性不高, Noyori 等[14] 提出 Ru – BINAP – 手性二胺 – KOH 三元催化体系后, 这类酮的不对称加氢才取得突破。随后 Hexa – PHEMP、MeO – BIPHEP、Xyl – HexaPHEMP、Xyl – Tetra PHEMP 和 MeO – Xyl – BIMOP 等配体与各种二胺配合用于催化芳香酮加氢, 本课题组的 *p* – AlkoxylMeOBIPHEP 类配体在此类反应中也表现出了良好的活性[15]。总体看, 3,5 – 二取代的配体效果最好, 能获得更好的 *e. e.* 值[16], 目前被广泛应用的手性二胺主要有如图 3 所示的几种。

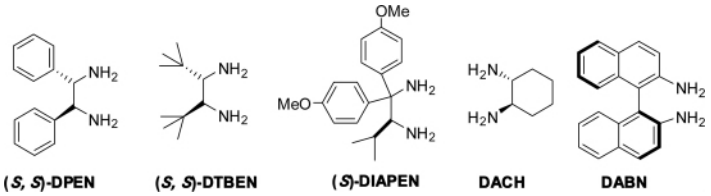

图 3　目前常用的催化未含官能团酮羰基的手性二胺

2004 年 Lipshutz 等采用了聚甲基含氢硅氧烷 PMHS 等硅氢化芳香酮氢化，是芳香酮不对称氢化的又一重要方法[17]，2012 年四川大学教授报道了 C_2 – 轴对称联苯类双膦配体参与的 CuH 催化芳香酮的不对称硅氢化反应，并进行了反应机理研究[18]。另 Riant 还以铜(I) 氟膦配合物为催化剂考察了此类反应中空气对反应的加速作用，研究认为空气的存在对反应存在一定的促进作用，其机理尚不明确[19]。C_2 – 轴对称手性双膦配体催化芳香酮氢化反应效果见表 2。

表 2　C_2 – 轴对称手性双膦配体催化芳香酮氢化反应

Catalyst	Sub.	yield/%	*e. e.* /%	ref
trans – $RuCl_2$ 【S) – BINAP】【S,S) – DIAPEN	A	99	97	14
trans – $RuCl_2$ 【R) – MeO – BIPHEP】【R,R) – DPEN	A	99	84	11
trans – $RuCl_2$ 【R) – HexaPHEMP】【R,R) – DAIPEN	A	99	90	11
trans – $RuCl_2$ 【S) – Xyl – HexaPHEMP】【S,S) – DPEN	A	99	99	11
trans – $RuCl_2$ 【S) – Xyl – HexaPHEMP】【S,S) – DPEN	B	99	99	11
trans – $RuCl_2$ 【R) – Xyl – TetraPHEMP】【R,R) – DPEN	A	99	99	20
trans – $RuCl_2$ 【R) – MeO – Xyl – BIMOP】【R,R) – DPEN	A	100	97	20
trans – $RuCl_2$ 【R) – MeO – BIPHEP】【R,R) – PEG – 2	A	99	92	21
trans – $RuCl_2$ 【R) – p – AlkoxylMeOBIPHEP】【R,R) – DPEN	A	99	92	15
trans – $RuCl_2$ 【R) – p – AlkoxylMeOBIPHEP】【R,R) – DPEN	C	99	99	15
【RuH(η^6 – arene) MeO – BIPHEP】(CF_3SO_3)	A	20	20	22
CuCl,PMHS,Xyl – MeO – BIPHEMP	A	94	17	
CuCl,PMHS,4 – MeO – 3,5 – DTBM – MeO – BIPHEMP	A	99	17	
CuCl,PMHS,DTBM – SEGPHOS	A	95	17	
CuF(PPh_3) $_3$ / BINAP/ $PHSiH_3$	A	>98	75	19
CuF(PPh_3) $_3$ /MeO – BIPHEP/ $PHSiH_3$	A	>98	75	19
CuF(PPh_3) $_3$ /3,5 – Dimethyl – MeO – BIPHEP/ $PHSiH_3$	A	75	19	
CuF(PPh_3) $_3$ /3,5 – Di – iPr – MeO – BIPHEP/ $PHSiH_3$	A	73	19	
CuF(PPh_3) $_3$ /3,5 – Di – tBu – – MeO – BIPHEP/ $PHSiH_3$	A	91	19	
CuF(PPh_3) $_3$ /4 – MeO_3,5 – Di – tBu – MeO – BIPHEP/PMHS	A	95	19	

注 1：催化氢化的反应条件为 *t* – BuOK，*i* – PrOH，8 atm H，25 ~ 30℃，30 min；

注 2：trans – $RuCl_2$ 【R) – MeO – BIPHEP】【R,R) – PEG – 2】为 PEG 负载手性多相催化剂[21]。

除苯乙酮外，C_2 – 轴对称膦配体也被用于其他未含官能团杂环酮羰基的不对称催化氢化，如 α – 吡啶酮[23]、哌啶酮[24]和噻吩酮[25 – 26]，如图 4 所示。

3.3　不对称催化氢化酮酸酯类化合物

1987 年 Noyori 等报道了首例【RuX2(BINAP)】配合物在温和条件下催化 β – 酮酸酯加氢，产物光学纯度接近 100%，产率几乎定量[27]，由此多种 C_2 – 轴对称膦配体同样被广泛地应用于 β – 酮酸酯的不对称催化氢化反应。

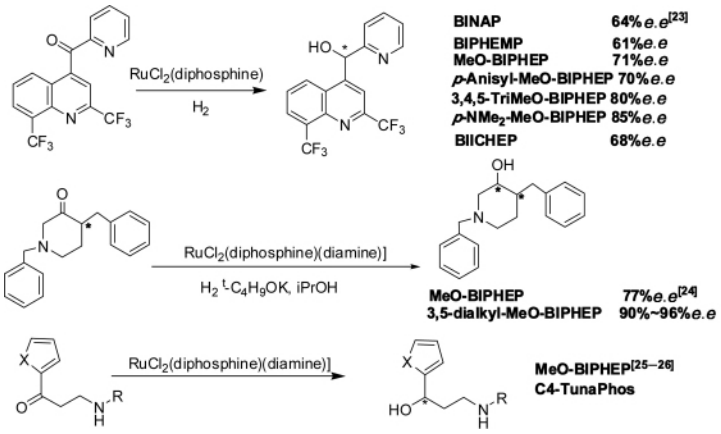

图 4 催化氢化其他未含官能团的芳香酮羰基

表 3 C_2 – 轴对称手性双膦配体催化 β – 酮酸酯化反应

Catalyst	Sub.	Reaction Condition	Con/%	*e. e.* /%	ref
$RuCl_2$ [BINAP], $RuBr_2$ [BINAP]	A	MeOH, rt, 100atm, 40h	100	99	27, 28
$RuCl_2$ [BINAP], $RuBr_2$ [BINAP]	B	MeOH, rt, 100atm, 40h	100	85	27, 28
$RuCl_2$ [BINAP], $RuBr_2$ [BINAP]	C	MeOH, rt, 100atm, 40h	100	99	27, 28
[BIPHEMP] $RuBr_2$	A	MeOH, 80℃, 10atm, 1h	100	99	29
[MeO – BIPHEP] $RuBr_2$	A	MeOH, 50℃, 20atm, 48h	100	99	3
[MeO – BIPHEP] $RuBr_2$	B	MeOH, 70℃, 100atm, 2h	100	86	3
MeO – BIPHEP – S($RuOCOCF_3$) $_2$	A	MeOH, 50℃, 10atm, 44h	100	93	3
MeO – BIPHEP – S [Rh(cod)] Cl	A	H2O, 50℃, 10atm, 44h	64	53	3
C_4 – Tunaphos [Ru(C_6H_6) Cl_2] $_2$	A	MeOH, 60℃, 52atm, 20h	99	99	30
C_4 – Tunaphos [Ru(C_6H_6) Cl_2] $_2$	B	MeOH, 60℃, 52atm, 20h	99	82	30
C_4 – Tunaphos [Ru(C_6H_6) Cl_2] $_2$	C	MeOH, 60℃, 52atm, 20h	99	99	30
[NH_2Me_2] { RuCl(SEGPHOS) } $_2Cl_3$]	C	MeOH, 80℃, 30atm, 6h	100	98	31
Ru($SYNPHOSCl_2$) DMF_n	A	MeOH, 90, 3.5atm, 24h	100	98	32
Ru – L_6 – Cl_2(DMF) $_n$	A	EtOH, 70℃, 3atm, 24h	100	99	33
Ru – L_6 – Cl_2(DMF) $_n$	B	EtOH, 70℃, 3atm, 24h	100	98	33
MeO – NAPhePHOS [cod) Ru(allyl) $_2$]	A	MeOH, 50℃, 50atm, 3h	100	97	34
MeO – NAPhePHOS [cod) Ru(allyl) $_2$]	E	EtOH, 80℃, 10atm, 24h	100	99	34
MeO – NAPhePHOS [cod) Ru(allyl) $_2$]	D	EtOH, 110℃, 10atm, 1h	100	32	34
TriMeNAPhePHOS [cod) Ru(allyl) $_2$]	A	MeOH, 50℃, 50atm, 3h	100	99	35
TriMeNAPhePHOS [cod) Ru(allyl) $_2$]	E	EtOH, 80℃, 10atm, 24h	100	93	35
TriMeNAPhePHOS [cod) Ru(allyl) $_2$]	D	EtOH, 110℃, 10atm, 1h	100	32	35
MeO – BIPHEP($RuBr_2$)	A	EtOH, 50℃, 4atm, 24h	100	99	36
MeO – BIPHEP($RuBr_2$)	B	MeOH, 50℃, 1atm, 18h	90	97	36
MeO – BIPHEP($RuBr_2$)	F	MeOH, 65℃, 1atm, 48h	100	94	36
SYNPHOS($RuBr_2$)	A	MeOH, 50℃, 4atm, 24h	100	99	5, 31, 37
SYNPHOS($RuBr_2$)	C	MeOH, 50℃, 4atm, 24h	100	99	5, 31, 37
SYNPHOS($RuBr_2$)	D	EtOH, 99℃, 10atm, 1h	100	49	5, 31, 37
MeO – BIPHEP($RuBr_2$)	G	EtOH, 50℃, 100atm, 96h	100	87	38, 39, 40

表 3(续)

Catalyst	Sub.	Reaction Condition	Con/%	*e. e.* /%	ref
Difluorphos($RuBr_2$)	A	MeOH, 50℃, 4atm, 24h	100	99	41,42
Difluorphos($RuBr_2$)	E	EtOH, 80℃, 10atm, 24h	100	92	41,42
Difluorphos($RuBr_2$)	D	EtOH, 110℃, 10atm, 1h	100	70	41,42
SYNPHOS($RuBr_2$)	A	MeOH, 50℃, 4atm, 24h	100	99	41,42
SYNPHOS($RuBr_2$)	E	EtOH, 80℃, 10atm, 24h	100	97	41,42
SYNPHOS($RuBr_2$)	D	EtOH, 110℃, 10atm, 1h	100	85	41,42
SEGPHOS ($RuBr_2$)	D	EtOH, 110℃, 10atm, 1h	100	59	41,42
(Ru L_7 Cl_2) (DMF) *n*	A	EtOH, 70℃, 3.5atm, 1h	100	99	41
(Ru L_7 Cl_2) (DMF) *n*	E	EtOH, 70℃,3.5atm, 24h	100	96	41
[Ru(R,S) – L_{14}(dmf) $_n$]	E	EtOH, 80℃,50atm, 12h	100	78	43
[Ru(S,S) – L_{14}(dmf) $_n$]	E	EtOH, 80℃,50atm, 12h	100	89	43
[RuL_{13}(dmf) $_n$]	E	EtOH, 80℃,50atm, 12h	100	83	43
[Ru(pAlkoxylMeOBIPHEP) PhCl] Cl	H	EtOH, 60℃,40atm, 17h	100	98	44

C_2 – 轴对称联苯类手性双膦配体同样也被应用于 α – 酮酸酯不对称催化加氢反应,结果如表 4 所示。

表 4　C_2 – 轴对称手性双膦配体催化 α – 酮酸酯氢化反应

Catalyst	Sub.	Reaction Condition	Con/%	*e. e.* /%	ref.
[NH_2Me_2] {RuCl(SEGPHOS)}$_2Cl_3$]	A	EtOH,50℃,50atm, 17h	100	97	31
[NH_2Me_2] {RuCl(SEGPHOS)}$_2Cl_3$]	B	EtOH,50,50atm, 17h	99	99	31
Ru(SYNPHOSCl_2) DMF*n*	C	EtOH,50℃,20atm,24h	100	94	5,30,37
Ru(SYNPHOSCl_2) DMF*n*	D	MeOH,50℃,20atm,24h	100	92	5,30,37
SYNPHOS ($RuBr_2$)	C	MeOH,50℃,20atm,24h	100	92	41
MeO – BIPHEP($RuBr_2$)	C	MeOH,50℃,20atm,24h	100	92	5,30,37
Difluorphos($RuBr_2$)	C	MeOH,50℃,20atm,24h	100	67	41
SYNPHOS ($RuBr_2$)	D	EtOH,50℃,20atm,24h	100	94	41
MeO – BIPHEP($RuBr_2$)	D	EtOH,50℃,20atm,24h	100	94	41
Difluorphos($RuBr_2$)	D	EtOH,50℃,20atm,24h	100	87	41
TriMe – NAPhePHOS [cod) Ru(allyl) $_2$]	C	MeOH,50℃,20atm,24h	100	85	35
MeO – NAPhePHOS [cod) Ru(allyl) $_2$]	C	MeOH,50℃,20atm,24h	100	75	35
MeO – BIPHEP [cod) Ru(allyl) $_2$]	C	MeOH,50℃,20atm,24h	100	90	35
(Ru L_7 Cl_2) (DMF) *n*	C	MeOH,rt,20atm,15h	>99	97	12
MeO – BIPHEP [cod) Ru(allyl) $_2$]	C	MeOH,40℃,80atm,24h	100	55	19
[Rh L_{17}(nbd) $_2$] BF_4	C	MeOH,40℃,80atm,24h	100	76	8
MeO – BIPHEP [Ru(p – cymene) I_2] $_2$	E	MeOH,60℃,80atm,24h	100	94	45
Tol – MeOBIPHEP [Ru(p – cymene) I_2] $_2$	E	MeOH,60℃,80atm,24h	100	93	45
BICHEP [Ru(p – cymene) I2] 2	E	MeOH,60℃,80atm,24h	100	88	45
[Ru(R,S) – L_{14}(dmf) $_n$]	C	MeOH,rt,20atm,20h	100	85	35
[Ru(S,S) – L_{14}(dmf) $_n$]	C	MeOH,rt,20atm,20h	100	95	35
[RuL_{13}(dmf) $_n$]	C	MeOH,rt,20atm,20h	100	90	35
Ru C_3 – Tunaphos (dmf) $_n$]	C	MeOH,rt,20atm,20h	>99	97	35

注: L_{17} 络合物循环 11 次后产物 *e. e.* 值保持不变。

β－酮－α－氨基酸酯进行不对称催化氢化研究较少，如 Genet 等以 MeO－BIPHEP 和 SYNPHOS 的 Ru 络合物[46]，Hamada 等以 MeO－BIPHEP 的 Ir 和 Ru 络合物为催化剂[47－48]研究了此反应体系，如图 5 所示。

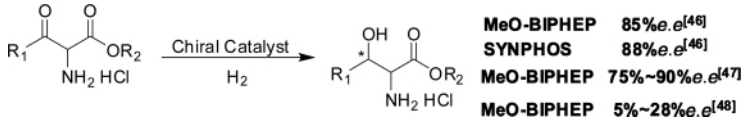

图 5 β－酮－α－氨基酸酯进行不对称催化氢化

3.4 不对称催化 α，β－不饱和化合物加氢

衣康酸（R = CH2COOH）、N－乙酰脱氢丙氨酸（R = NHCOMe）和萘普生前体（R = 6－MeO－Naphthalene）等 α，β－不饱和酸不对称加氢是合成多种药物的重要反应，C_2－轴对称膦配体在其中发挥了重要的作用，如表 5 所示。

表 5 C_2－轴对称手性双膦配体催化衣康酸类化合物氢化反应

Catalyst	R	Reaction Condition	Con/%	*e. e.* /%	ref.
[BICHEP－Rh(nbd)]$^+$Cl$^-$	A	THF，rt，1 atm，10min	100	99	2
[BIPHEMP] $RuBr_2$	B	MeOH，80℃，10atm，1h	—	50	29
[BIPHEMP] $RuBr_2$	C	MeOH，80℃，10atm，1h	—	77	29
[BIPHEMP] $RuBr_2$	D	MeOH，80℃，10atm，1h	—	45	29
[MeO－BIPHEP] $RuBr_2$	B	MeOH，80℃，10atm，1h	—	93	29
TriMe－NAPhePHOS $RuBr_2$	A	MeOH，50℃，4atm，24h	100	89	35
MeO－NAPhePHOS $RuBr_2$	A	MeOH，50℃，4atm，24h	100	90	35
[MeO－BIPHEP] $RuBr_2$	A	MeOH，50℃，4atm，24h	100	90	35
Difluorphos($RuBr_2$)	A	MeOH，50℃，20atm，1h	100	85	41
SYNPHOS($RuBr_2$)	A	MeOH，50℃，20atm，1h	100	92	41
MeO－BIPHEP ($RuBr_2$)	A	MeOH，50℃，20atm，1h	100	90	41
Ru【SYNPHOS) Cl(p－cymene)】Cl	D	MeOH，rt，120atm，1h	100	92	32
Ru－L_6－Cl_2(DMF)$_n$	D	MeOH，rt，120atm，4h	100	93	33
Ru－Cl－MeO－BIPHEP－Cl_2(DMF)$_n$	B	MeOH，rt，1atm，6h	100	92	9

C_2－轴对称联苯类膦配体也常用于如巴豆酸等 α，β－不饱和酸不对称加氢反应[30－49]，如图 6 所示。C_2－轴对称配体在合成具有此类结构单元的药物中也发挥重要的作用[49－50]。

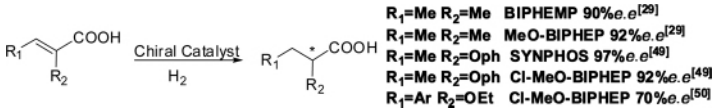

图 6 催化氢化巴豆酸等 α，β－不饱和酸

不对称氢化环烯酮类 α，β－不饱和化合物也具有重要应用价值，Lipshutz 等以 Cu 为中心金属络合 3，5 二取代配体 DTBM－SEGPHOS 和 Xyl－MeO－BIPHEP 在 PMHS 存在下对位阻较大的 β－取代环烯酮 1，4－催化氢化还原[51－52]，如图 7 所示。Buchwald 在木酚素的合成中采用 MeO－BIPHEP 和 SYNPHOS 配体，在 PMHS 的催化下对 α，β－不饱和内酯不对称硅氢化[53]。

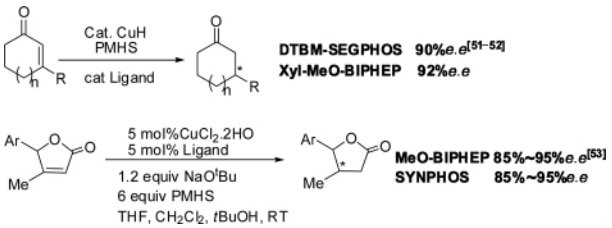

图 7 不对称 1，4－还原环烯酮类 α，β－不饱和化合物

C_2－轴对称配体可用于膦酸酯不对称共轭加成，大连化物所胡向平以 SYNPHOS、MeO－BIPHEP、DTBM－SEGPHOS 和 SEGPHOS 的 Cu 络合物催化（E）－（2－苯基－丙炔基）膦酸酯不对称共轭还原氢化[54]。2012 年上海有机所张兆国研究员报道了配体 L_{11} 高效不对称氢化反应的 β－酮膦酸酯

的反应，获得了良好的对映选择性(高达 99. 9% *e. e.* 值) 和优异的立体选择性(96∶4) [55] ，如图 8 所示。

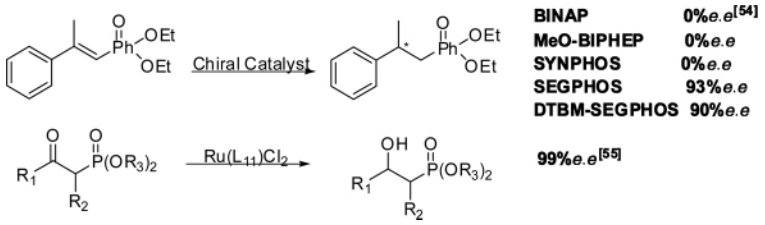

图 8　膦酸酯不对称共轭加成

3. 5　不对称催化氢化氮杂环、亚胺

周永贵研究员等[56 – 60]和陈新滋院士等[61]报道了多种配体 Ir 络合物催化 2 – 取代喹啉不对称氢化。周永贵研究员进一步研究了 Ir 络合物催化经氯甲酸酯活化的喹啉异喹啉[62]、四氢喹啉环外烯胺[63]、二氢喹啉酮[64]及 2 – 甲基喹喔啉[57]的不对称氢化。Henschke 也以 Hexa – PHEMP 和 Xyl – HexaPHEMP 为配体对 2 – 甲基喹喔啉进行了加氢反应研究[11]。

C_2 – 轴对称膦配体也用于催化环烯胺、亚胺加氢，如张绪穆等的 o – Ph – hexaMeO – BIPHEP 配体应用于 N – (3，4 – 脱氢 – 1 – 萘) 乙酰胺的加氢[65]；Henschke 将钌膦二胺络合物应用于 N – (苯基) – 苯乙胺加氢[66]；周永贵以 SEGPHOS 和 SYNPHOS 为配体的 Pd 络合物催化活性亚胺的不对称氢化[67]。

碳氧双键 C = O、碳碳双键 C = C 和碳氮双键 C = N 上的立体选择性加氢是一个非常有效、高技术含量和经济可行的获得手性碳原子的方法，双膦配位络合物在对多种类型的底物的选择性加氢中发挥着至关重要的作用。C_2 – 轴对称联苯类双膦配体性的合成及其在不对称催化反应中的应用在不对称催化研究中占有非常重要的地位。不对称催化氢化环烯胺、亚胺流程如图 10 所示。

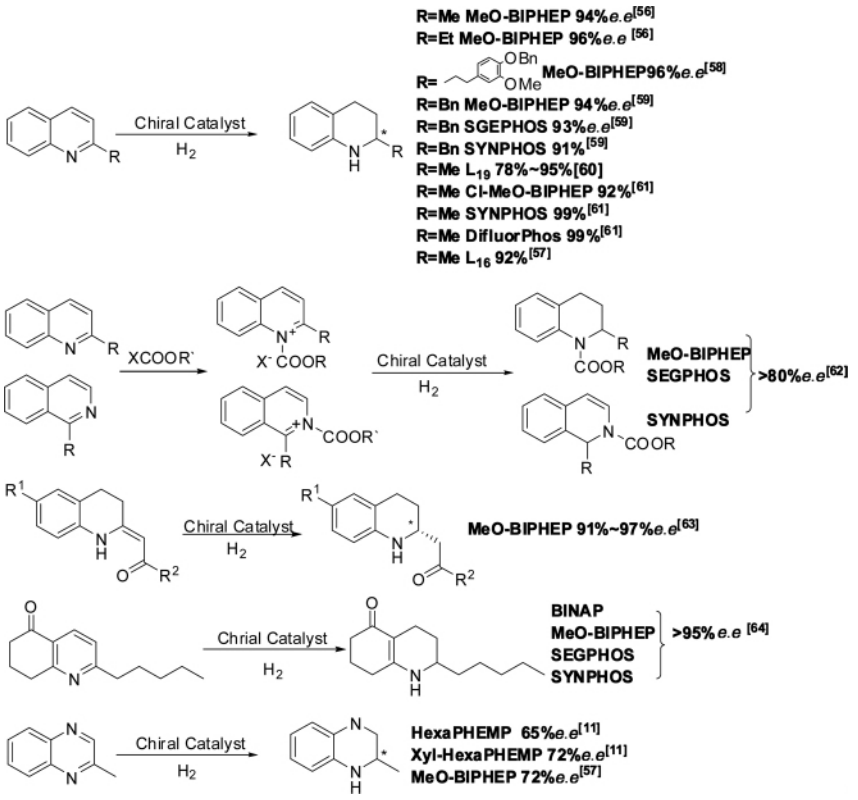

图 9　不对称催化氢化喹啉、异喹啉和喹喔啉

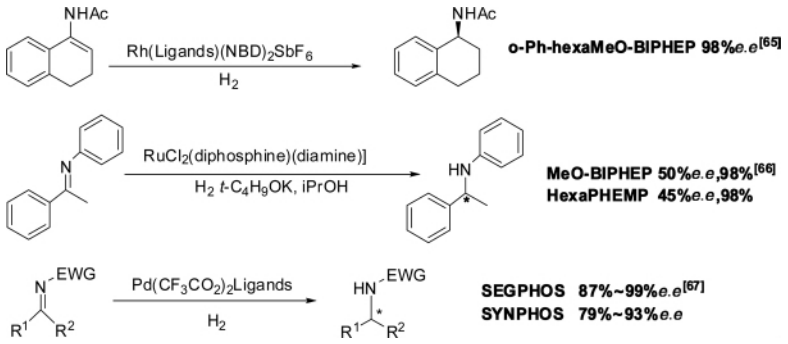

图 10 不对称催化氢化环烯胺、亚胺

虽然对 C_2 – 轴对称联苯类双膦配体在不对称催化反应中的研究已经有很大进展，但这一领域仍然有许多尚未解决的问题，开拓新型的不对称催化反应，利用不对称催化技术合成有生理活性的手性物质，对手性催化反应机理的研究，深入对不对称催化反应机理的认识等方面仍是将来需要进一步关注的研究领域。循环利用手性催化剂以便更合理更经济地使用这些昂贵的催化剂也是需要加强的一个研究方向。

（未完待续）

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(编校:叶超)