A Novel One-Pot Reaction: Zwitterionic Rhodium Complex-Catalyzed Hydroaminovinylation of Vinyl Sulfones and a Vinylphosphonate

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It is well-known that functionalized vinyl sulfones and phosphonates have wide applications in organic synthesis.[1] Nitrogen-containing vinyl sulfones and vinyl phosphonates are important intermediates involved in biochemical synthesis.[2,3] The development of new processes for synthesizing amino-substituted unsaturated sulfones and phosphonates has attracted considerable attention.[1b] One approach is the hydroaminomethylation of olefins as a one-pot synthesis of amines.[4,5] Recently, we have found that hydroaminomethylation of aryl-substituted ethylenes affords mainly branched chain amines, under relatively mild conditions, by using the zwitterionic rhodium complex $[Rh^+(cod)(\eta^6\text{-}PhBPh_3)^-]$ (**1**) as a catalyst.[6] These results stimulated us to explore the reactions of vinyl sulfones and a phosphonate under hydroaminomethylation conditions. A novel type of one-pot reaction, *hydroaminovinylation*, took place. We now report the results of this investigation.

Reaction of methyl vinyl sulfone (**2**), isopropylamine (**3a**), and 1:1 carbon monoxide/hydrogen (total pressure of 200 psi), with 1 mol % of **1** and **3** mol % of BINAP as an added phosphine ligand, for 24 h at 80 °C, afforded the sulfonylated enamine **4a** in 86% isolated yield (eq 1 and Table 1, entry 1).[7] The Michael-type addition product **5a** was a minor byproduct of the reaction. To our knowledge, this is the first example of the one-pot formation of a sulfonated enamine from the corresponding vinyl sulfone catalyzed by a rhodium complex. Various reaction conditions were examined for this hydroaminovinylation reaction (Table 1). For example, other chelating phosphine ligands, such as 1,4-bis(diphenylphosphino)butane (dppb) and 1,2-bis(diphenylphosphino) ethane (dppe) also afforded **4a** in good yields (entries 2 and 3). In contrast, **5a** was the principal product using bis-(diphenylphosphino)methane (dppm) as the ligand (entry 4). The

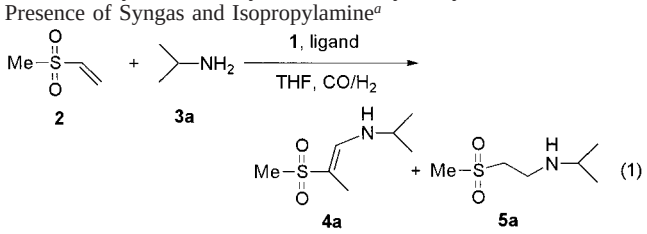
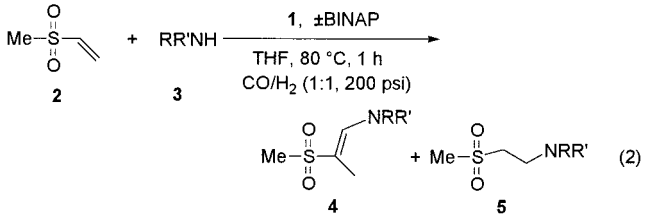


Table 1. Hydroaminovinylation of Methyl Vinyl Sulfone in the Presence of Syngas and Isopropylamine[a]

				yield (mol %)[b]	
entry	L (mol %)	*T* (°C)	CO/H_2 (psi)	**4a**	**5a**
1	±BINAP (3)	80	100/100	96 (86)	4
2[c]	dppb (3)	80	100/100	92 (87)	3
3	dppe (3)	80	100/100	93	7
4[d]	dppm (3)	80	100/100	17	49
5[c,e]	PPh_3 (6)	80	100/100	61	25
6[c,e]	PCy_3 (6)	80	100/100	10	61
7	none	80	100/100	0	100
8	±BINAP (3)	50	100/100	68	32
9	±BINAP (3)	80	100/500	95	5
10[f]	±BINAP (3)	80	100/100	94	6

[a] Reaction conditions: methyl vinyl sulfone (1 mmol), isopropylamine (1.2 mmol), **1** (0.01 mmol), phosphine, THF (5 mL), 24 h. [b] The yields were determined by ^1H NMR and GC (the isolated yield is given in parentheses). [c] A small amount of $MeSO_2CH_2CH_2SO_2Me$ (<4 mol %) was formed. [d] Methyl vinyl sulfone (34%) was recovered. [e] Unidentified byproducts were formed (14% in entry 5, and 29% in entry 6). [f] The reaction was carried out for 1 h.

Table 2. Hydroaminovinylation of Methyl Vinyl Sulfone in the Presence of Various Amines[a]



R = *n*-Bu, *t*-Bu, cyclohexyl, benzyl, and Ph; R' = H; R = R' = Et

		yield (mol %)[b]	
entry	amine	**4**	**5**
1	butylamine (**3b**)	66 (43, **4b**)	34 (**5b**)
2	*tert*-butylamine (**3c**)	100 (89, **4c**)	0
3	cyclohexylamine (**3d**)	90 (75, **4d**)	10 (**5d**)
4	benzylamine (**3e**)	87 (67, **4e**)	13 (**5e**)
5	aniline (**3f**)	100 (73, **4f**)	0
6	$HNEt_2$ (**3g**)	84 (66, **4g**)	16 (**5g**)

[a] Reaction conditions: methyl vinyl sulfone (1 mmol), amine (1.2 mmol), **1** (0.01 mmol), ±BINAP (0.03 mmol), THF (5 mL), 80 °C for 1 h. [b] The yields were determined by ^1H NMR and GC (isolated yield is given in parentheses).

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(7) See Supporting Information for general procedures and details on the ^1H, ^{13}C, ^{31}P NMR, MS, and HRMS of the enamines.

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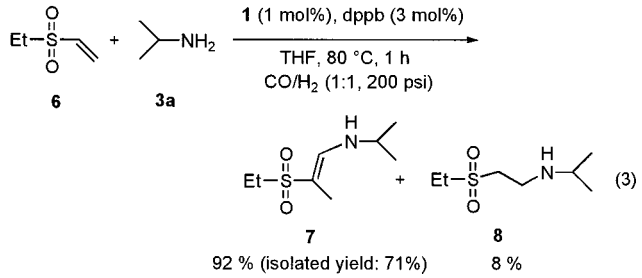
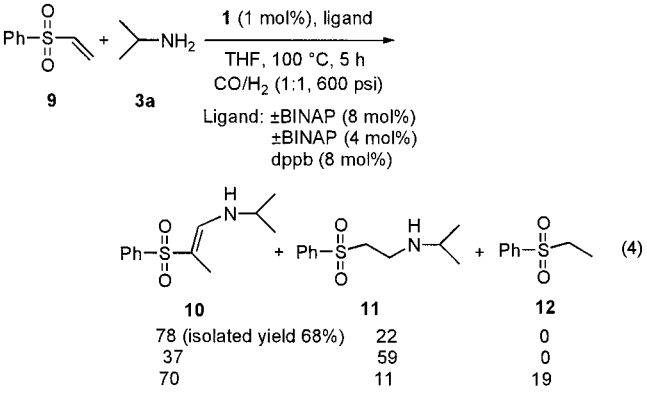
reason for this change in behavior is not clear. While the use of a monodentate phosphine, triphenylphosphine, resulted in the formation of **4a** in 61% yield (entry 5), the more basic and sterically encumbered ligand, tricyclohexylphosphine, was of little value here (entry 6). In the absence of a phosphine ligand, **5a** was formed exclusively (entry 7). Consequently BINAP, dppb, and dppe are effective ligands for the hydroaminovinylation reaction. A decrease of the reaction temperature to 50 °C resulted in reducing the selectivity to form **4a** (entry 8). Interestingly, reduction of the double bond in **4a** did not occur even though the hydrogen pressure was increased to 500 psi (entry 9). It is noteworthy that the hydroaminovinylation of sulfones can be completed in only 1 h, that is, one does not have to let the reaction proceed for 24 h (entry 10).

The scope of the reaction was examined with a number of amines and vinyl sulfones. Fine yields of **4b**−**4g** were obtained using primary amines (RNH_2, R = *n*-C_4H_9, *t*-C_4H_9, C_6H_{11}, $PhCH_2$, and Ph, Table 2, entries 1−5) and diethylamine (entry 6).

Hydroaminovinylation of ethyl vinyl sulfone gave the corresponding unsaturated enamine **7** in good yield, with dppb as the ligand (eq 3). Phenyl vinyl sulfone is less active toward



hydroaminovinylation compared with methyl vinyl sulfone. The addition reaction is the principal process when less than 4 equiv of ±BINAP was used for the reactions (eq 4). However,



increasing the amount of the ligand to 8 equiv significantly impacted the degree of hydroaminovinylation, leading to the formation of **10** in 78% yield as the major product (eq 4). Use of 8 mol % dppb as the ligand instead of ±BINAP resulted in the formation of **10** in a similar yield. Likewise, a sulfoxide, phenyl vinyl sulfoxide, was converted to the corresponding enamine **14** in high yield by the described methodology (89%, eq 5).

The hydroaminovinylation of diethyl vinylphosphonate proceeded smoothly in the presence of a primary or secondary amine, using **1**/dppb as the catalyst system, affording only the phosphorus-containing vinylated amine **17a**−**h**, in 63−88% isolated yields (eq 6, Table 3). The primary amines, except aniline, gave **17** as

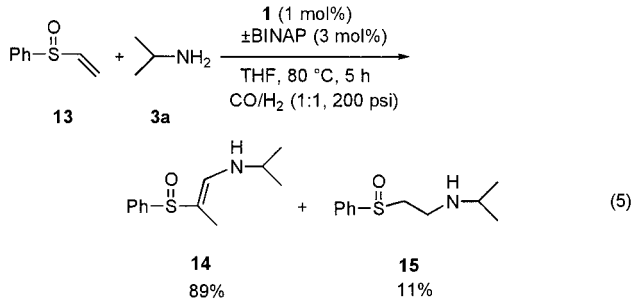
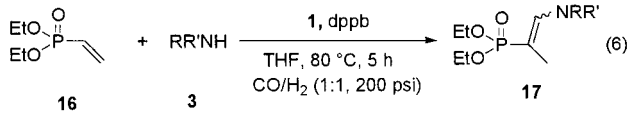


Table 3. Hydroaminovinylation of Diethyl Vinylphosphonate in the Presence of Amines[a]



R = *i*-Pr, *n*-Bu, *t*-Bu, benzyl, and Ph; R′ = H; R = R′ = Et; R + R′ = piperidine

entry	amine	yield (mol %)[b]	ratio trans/cis
1	isopropylamine (**3a**)	100 (83, **17a**)	88:12
2	butylamine (**3b**)	98 (63, **17b**)	86:14
3	*tert*-butylamine (**3c**)	97 (66, **17c**)	88:12
4[c]	benzylamine (**3e**)	96 (88, **17e**)	80:20
5[d]	aniline (**3f**)	95 (70, **17f**)	100:0
6	$HNEt_2$ (**3g**)	100 (84, **17g**)	100:0
7	piperidine (**3h**)	100 (82, **17h**)	100:0

[a] Reaction conditions: diethylvinylphosphonate (1 mmol), amine (1.2 mmol), **1** (0.01 mmol), dppb (0.03 mmol), THF (5 mL), 80 °C for 5 h. [b] The yields were determined by ^1H NMR and GC (the isolated yield is given in parentheses). [c] $(EtO)_2P(O)CH(CH_3)CHO$ (4%) was formed. [d] 5% of unidentified byproducts.

a mixture of trans- and cis-isomers (based on ^1H and ^{31}P NMR spectroscopy), with good selectivity for the trans-isomer. The fact that only *trans*-enamines were formed when the secondary amines, diethylamine and piperidine, were used indicates that the proton attached to the nitrogen atom plays an important role in forming the cis-isomer when the primary amine is employed. Intramolecular hydrogen-bonding between the H atom of the NH group and the O atom of the P═O moiety may be responsible for the formation of some of the cis-isomer in the case of primary amines. The formation of six-membered lithiated enaminoalkylphosphonates has been reported in the preparation of α,*β*-unsaturated α-substituted aldehydes.[8] The weakly electron-withdrawing phenyl group in aniline probably diminishes hydrogen-bond formation in **17f**, which may be why only the trans-isomer is formed here.

In conclusion, a new one-pot hydroaminovinylation reaction has been achieved for the synthesis of sulfonated and phosphonated enamines using the zwitterionic rhodium complex **1** together with a chelating phosphine ligand as the catalyst. The regio- and stereoselectivity of the reactions are often excellent.

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Supporting Information Available: General procedures, ^1H, ^{13}C, ^{31}P NMR, MS, and HRMS of enamines **4**, **7**, **10**, **14**, and **17** (PDF). The material is available free of charge via the Internet at http://pubs.acs.org.

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