Highly Enantioselective Intramolecular Cyclopropanation Reactions of *N*-Allylic-*N*-methyldiazoacetamides Catalyzed by Chiral Dirhodium(II) Carboxamidates

Michael P. Doyle* and Alexey V. Kalinin

Department of Chemistry, Trinity University, San Antonio, Texas 78212

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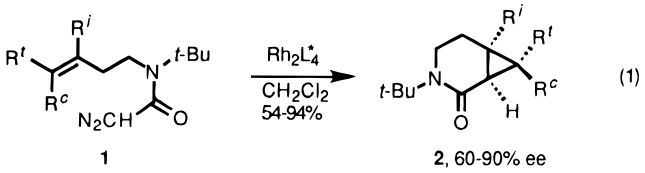
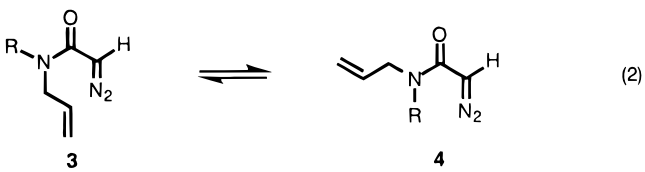
Catalytic diazo decomposition of representative *N*-allylic-*N*-methyldiazoacetamides produced the corresponding intramolecular cyclopropanation products in good to excellent yields and with exceptional enantiocontrol. In the simplest case, with *N*-allyl-*N*-methyldiazoacetamide, catalysis by dirhodium(II) tetrakis[methyl 2-oxapyrrolidine-5(*S*)-carboxylate], Rh_2(5(*S*)-MEPY)$_4$, achieved the highest yield and enantioselectivity (93% ee). Dirhodium(II) tetrakis[methyl 2-oxo-1-(3-phenylpropanoyl)imidazolidin-4(*S*)-carboxylate], Rh_2(4*S*)-MPPIM)$_4$, was preferred for substituted *N*-allylic-*N*-methyldiazoacetamides from which 92−95% ee's were obtained in intramolecular cyclopropanation reactions (88−95% yields), even when the catalyst was employed in only 0.1 mol %. Competition with intramolecular dipolar cycloaddition was minimized with the use of *N*-methyldiazoacetamides relative to *N*-*tert*-butyldiazoacetamides.

We recently reported that the homoallylic *N*-*tert*-butyl-*N*-(3-buten-1-yl)diazoacetamides (**1**) underwent intramolecular cyclopropanation catalyzed by dirhodium(II) tetrakis[methyl 2-oxapyrrolidine-5(*S*)-carboxylate], Rh_2-(5(*S*)-MEPY)$_4$, or dirhodium(II) tetrakis[methyl 2-oxo-oxazolidine-4(*S*)-carboxylate], Rh_2(4(*S*)-MEOX)$_4$, in good yields and with enantiomeric excesses ranging from 60 to 90% (eq 1),[1] but we were frustrated in our attempts to



1 **2**, 60-90% ee (1)

effect intramolecular cyclopropanation with their allylic analogs by an unexpectedly facile [3 + 2] cycloaddition to form pyrazolines.[2] Only *N*,*N*-diallyldiazoacetamide was competitively transformed to the intramolecular cyclopropanation product, but its yield was low and its enantiomeric excess was only 72%.[1] The amide functionality exacts a conformational rigidity on the diazoacetamide[3] that with a *N*-*tert*-butyl substituent favors **3**, which is suitably aligned for intramolecular cycloaddition as well as for eventual intramolecular cyclopropanation. We reasoned that if the *tert*-butyl group was replaced by H (R = *t*-Bu → R = H, eq 2), the preferred conformation

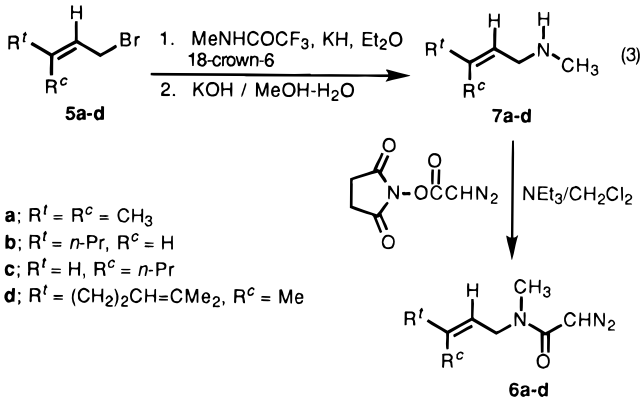


3 **4** (2)

would be **4** and, as was demonstrated in attempted catalytic cyclopropanation with *N*-allyldiazoacetamides,[4] intramolecular reactions would be frustrated by the lack of proximity of the double bond to the diazo or metal carbene enter. However, if the substituent is methyl, there was expected to be a balance between **3** and **4** so that, relative to R = *t*-Bu, dipolar cycloaddition might occur on a time scale that was significantly less than that for intramolecular cyclopropanation. We now wish to report that *N*-allylic-*N*-methyldiazoacetamides undergo intramolecular cyclopropanation with high enantiocontrol and without extensive competition from intramolecular dipolar cycloaddition.

Results and Discussion

Diazoacetamides were prepared in good yields from allylic bromides by methylamine substitution[5] followed by direct diazoacetyl transfer from succinimidyl diazoacetate[6] (eq 3), for which we have developed an improved



method for synthesis. This diazoacetylation procedure is preferred over the diketene condensation−diazo trans-

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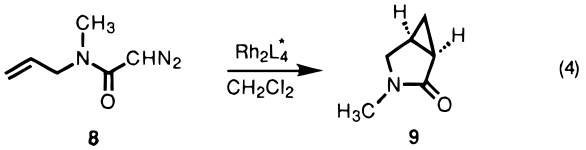
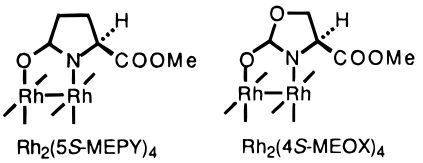
fer−deacylation methodology[1,7] because it avoids the production of *N*-allylic diazoacetoacetamides which are more susceptible than are *N*-allylic diazoacetamides toward dipolar cycloaddition.[2] Furthermore, succinimidyl diazoacetate is a stable, easily stored solid that is highly selective toward diazoacetyl transfer to amines and phenols.[6]

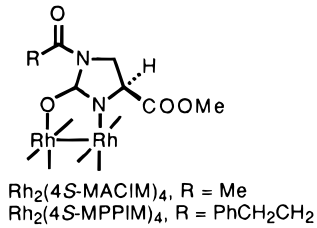
Diazo decomposition of *N*-allyl-*N*-methyldiazoacetamide (**8**) was accomplished in refluxing CH_2Cl_2 (eq 4)



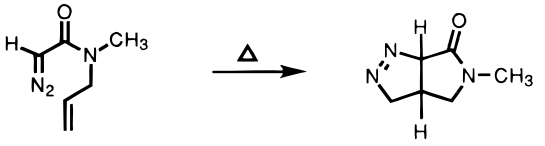
(4)

8 **9**





with chiral dirhodium(II) carboxamidate catalysts chosen to evaluate optimization of enantiocontrol: Rh_2(5(*S*)-MEPY)$_4$;[8] Rh_2(4(*S*)-MEOX);[9] dirhodium(II) tetrakis[methyl 1-acetyl-2-oxoimidazolidine-4(*S*)-carboxylate], Rh_2(4(*S*)-MACIM)$_4$;[10] and dirhodium(II) tetrakis[methyl 2-oxo-1-(3-phenylpropanoyl)imidazolidine-4(*S*)-carboxylate], Rh_2(4(*S*)-MPPIM)$_4$.[11] Rhodium(II) acetate and rhodium(II) caprolactamate, Rh_2(cap)$_4$,[12] catalyzed reactions were performed to obtain racemic products and to estimate the relative extent of competing reactions with the use of achiral catalysts. As seen from Table 1, the highest % ee and isolated yield were achieved with Rh_2(5(*S*)-MEPY)$_4$. Dipolar cycloaddition of **8** (eq 5) was



(5)

8 **10**

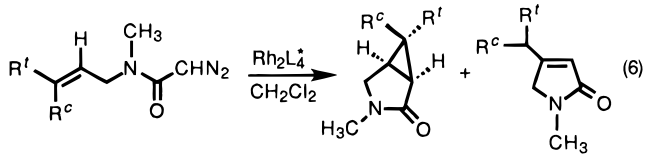
competitive with intramolecular cyclopropanation and caused the lower than optimal yields of **9**; the half-life for pyrazoline formation from **8** was approximately 25 h at 22 °C. In refluxing chloroform, **10** was obtained in quantitative yield within 2.5 h. Enantiomeric excesses were determined by GC analyses on a chiral capillary column, and unless the pyrazoline byproduct was completely separated from the catalytic cyclopropanation product, reduced % ee values (up to 12%) were observed, presumably due to dinitrogen loss from the pyrazoline.[13] The absolute configuration of **9** was established to be 1*R*,5*S* by comparison (rotation and GC) of **9** with the product from *N*-methylation of (1*R*,5*S*)-3-azabicyclo[3.1.0]-hexan-2-one.[4]

Table 1. Catalytic Intramolecular Cyclopropanation of *N*-Allyl-*N*-methyldiazoacetamide (8)[a]

catalyst	yield, %, of **9**[b]	% ee of **9**[c]
Rh_2(5(*S*)-MEPY)$_4$	62	93
Rh_2(4(*S*)-MEOX)$_4$	45	86
Rh_2(4(*S*)-MACIM)$_4$	23	56
Rh_2(4(*S*)-MPPIM)$_4$	20	75
Rh_2(cap)$_4$	33	
Rh_2(OAc)$_4$	41	

[a] Reactions were performed in refluxing CH_2Cl_2 using 1.0 mol % of catalyst. [b] Isolated yield of purified product. [c] Determined by capillary GC with base line resolution on a Chiraldex G-TA column.

Catalytic intramolecular cyclopropanation of representative substituted *N*-allylic-*N*-methyldiazoacetamides (eq 6) occurred without noticeable competition from dipolar

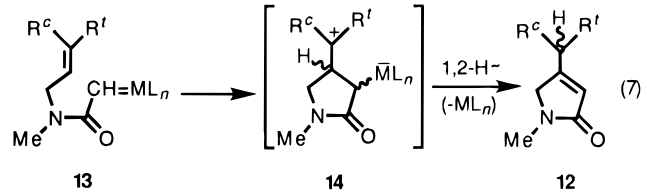


(6)

7a-d **11a-d** **12a-d**

cycloaddition and produced cyclopropane-fused γ-lactams **11** in high yield and with exceptional enantiocontrol (Table 2). The preferred catalyst was Rh_2(4(*S*)-MPPIM)$_4$, which could be effectively employed in as little as 0.1 mol % to achieve the highest levels of enantiocontrol and the lowest amount of the competing product **12**. Absolute configurations are those depicted for **11a**−**d**; they were inferred from **9** and from their sign of rotation relative to that of their lactone analogs whose absolute configuration is known.[4,8]

The formation of **12** is consistent with stepwise intramolecular electrophilic addition of the metal carbene (**13**) to the carbon−carbon double bond (eq 7), forming



(7)

13 **14** **12**

an intermediate carbocation **14** that produces **12** following 1,2-hydrogen migration and elimination of ML_n.[14] An identical transformation to that described in eq 7 has

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Table 2. Influence of Dirhodium(II) Catalysts on Product Selectivity in Intramolecular Cyclopropanation Reactions of 7[a]

7	R^t	R^c	catalyst	yield,[b] %	**11**:**12**	% ee of **11**[c]	config[d]
a	Me	Me	Rh_2(5(*S*)-MEPY)$_4$	92	98:2	86	(1*S*,5*R*)
			Rh_2(4(*S*)-MEOX)$_4$	91	83:17	94	(1*S*,5*R*)
			Rh_2(4(*S*)-MACIM)$_4$	82	>99:<1	81	(1*S*,5*R*)
			Rh_2(4(*S*)-MPPIM)$_4$[e]	88	>99:<1	94	(1*S*,5*R*)
			Rh_2(cap)$_4$	49	97:3		
			Rh_2(OAc)$_4$	70	82:18		
b	*n*-Pr	H	Rh_2(5(*S*)-MEPY)$_4$	93	>99:<1	86	(1*R*,5*S*)
			Rh_2(4(*S*)-MEOX)$_4$	93	98:2	57	(1*R*,5*S*)
			Rh_2(4(*S*)-MPPIM)$_4$	93	99:1	92	(1*R*,5*S*)
			Rh_2(cap)$_4$	56	96:4		
			Rh_2(OAc)$_4$	60	97:1[f]		
c	H	*n*-Pr	Rh_2(5(*S*)-MEPY)$_4$	95	99:1	90	(1*R*,5*S*)
			Rh_2(4(*S*)-MEOX)$_4$	86	97:3	92	(1*R*,5*S*)
			Rh_2(4(*S*)-MPPIM)$_4$	88	99:1	95	(1*R*,5*S*)
			Rh_2(cap)$_4$	59	99:1		
			Rh_2(OAc)$_4$	54	87:13		
d	$(CH_2)_2CH{=}CMe_2$	Me	Rh_2(5(*S*)-MEPY)$_4$	98	98:2	92	(1*S*,5*R*)
			Rh_2(4(*S*)-MEOX)$_4$	94	83:17	94	(1*S*,5*R*)
			Rh_2(4(*S*)-MPPIM)$_4$[g]	95	>99:<1	93	(1*S*,5*R*)
			Rh_2(cap)$_4$	67	97:3		
			Rh_2(OAc)$_4$	77	79:21		

[a] Reactions were performed in refluxing CH_2Cl_2 using, unless specified otherwise, 1.0 mol % of catalyst. [b] Isolated yield of purified product (**11** + **12**). [c] Determined by capillary GC on a Chiraldex G-TA column with base line resolution. [d] Absolute configurations are as depicted for **11a**−**d**; change in notation results from change in priorities by substituents. [e] Catalyst amount was 0.1 mol %. [f] Two additional products, 1% each (not identified), were detected. [g] Catalyst amount was 0.2 mol %.

Table 3. Influence of Dirhodium(II) Catalysts on Product Selectivity in Intramolecular Reactions of *N*-(2-Methyl-2-propen-1-yl)-*N*-methyldiazoacetamide[a]

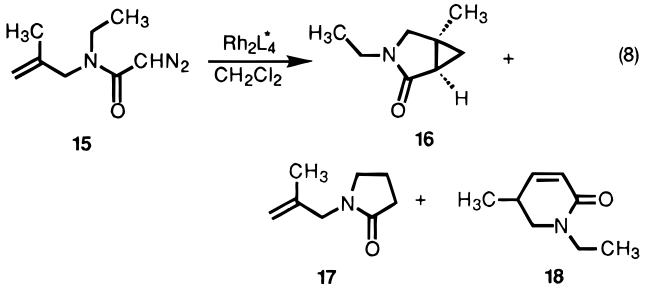
		relative yield			
catalyst	isolated yield, %	**16**	**17**	**18**	% ee **16**[b]
Rh_2(5(*S*)-MEPY)$_4$	78	98	<1	2	35
Rh_2(4(*S*)-MEOX)$_4$	81	92	<1	8	7[c]
Rh_2(4(*S*)-MACIM)$_4$	86	95	5	<1	48
Rh_2(4(*S*)-MPPIM)$_4$	85	94	6	<1	44
Rh_2(cap)$_4$	83	80	20	<1	
Rh_2(OAc)$_4$	71	70	30	<1	

[a] Reactions were performed in refluxing CH_2Cl_2 using 1.0 mol % of catalyst. [b] Determined by capillary GC with base line resolution on a Chiraldex B-PH column. [c] The predominant configuration was opposite that from other entries in this table.

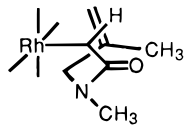
been reported in intramolecular cyclopropanation reactions of 3-methyl-2-buten-1-yl diazoacetate, the ester analog of **7a**, particularly with chiral dirhodium carboxamidates without pendent carbomethoxy substituents.[8] That **7a** and **7d** gave the highest relative yields of **12** is also consistent with the stepwise carbocation mechanism for its formation.

The highest levels of enantiocontrol achieved with chiral dirhodium(II) carboxamidates for the formation of **9** and **11** are only 2−4% ee lower than those previously reported for their lactone analogs,[4,15] and the absolute configuration of products formed by intramolecular cyclopropanation of diazoacetamides with the same catalyst configuration is identical. For example, the *S*-series of chiral dirhodium(II) carboxamidate catalysts forms (1*R*,5*S*)-**9**, whereas the *R*-series provides (1*S*,5*R*)-**9** with the same level of enantiocontrol. The only limitation with *N*-allylic-*N*-methyldiazoacetamide is dipolar cycloaddition which in our hands precluded intramolecular cyclopropanation of **7** (R^t = Ph, R^c = H).

2-Methyl-2-propen-1-yl diazoacetate was previously shown to be an anomoly among allylic diazoacetates in its resistance to high enantiocontrol in intramolecular cyclopropanation reactions catalyzed by chiral dirhodium(II) carboxamidates, and its *N*-ethyldiazoacetamide analog behaved similarly. Diazo decomposition of *N*-ethyl-*N*-(2-methyl-2-propen-1-yl)diazoacetamide (**15**) produced the product from intramolecular cyclopropanation (**16**) in good yield (eq 8), but enantioselectivity did not exceed



50% ee (Table 3). In addition, the product from carbene insertion into a methyl C−H bond of the *N*-ethyl substituent (**17**) was a major competing process with use of the achiral catalysts, although not with the chiral catalysts. Furthermore, in reactions catalyzed by Rh_2(5(*S*)-MEPY)$_4$ and Rh_2(4(*S*)-MEOX)$_4$ a product (**18**) consistent with intramolecular electrophilic addition of the metal carbene to the carbon−carbon double bond was detected. This product conforms to the chairlike transition state orientation (**19**) previously described for catalytic cyclopropanation of 2-methyl-2-propen-1-yl diazoacetate in which initial interaction occurs at the terminal carbon in order to optimize carbocation stabilization.



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Experimental Section

General Procedures. ^{1}H NMR (300 MHz) and ^{13}C NMR (75 MHz) spectra were obtained as solutions in $CDCl_3$, unless indicated otherwise, and chemical shifts are reported in parts

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per million (ppm, δ) downfield from internal Me_4Si (TMS). Mass spectra were obtained using electron ionization on a quadrupole instrument. Infrared spectra were recorded as a thin film on sodium chloride plates, and adsorptions are reported in wavenumbers (cm^{-1}). Elemental analyses were performed at Texas Analytical Laboratories, Inc. The preparations of $Rh_2(5(S)\text{-MEPY})_4$,[8] $Rh_2(4(S)\text{-MEOX})_4$,[9] $Rh_2(4(S)\text{-MACIM})_4$,[4] $Rh_2(4(S)\text{-MPPIM})_4$,[11] and $Rh_2(cap)_4$[12] have been previously reported. Dichloromethane was distilled from calcium hydride prior to use. *N*-methyl-*N*-(2-propen-1-yl)-amine and *N*-ethyl-*N*-(2-methyl-2-propen-1-yl)amine were commercially available.

Succinimidyl Diazoacetate. Glyoxylic acid chloride (*p*-toluenesulfonyl)hydrazone[16] (103.3 g, 0.500 mol) in 1.00 L of CH_2Cl_2 was added over 2 h to a mechanically stirred suspension of *N*-hydroxysuccinimide (63.25 g, 0.550 mol) and Na_2CO_3 (79.5 g, 0.750 mol) in 0.75 L of dry CH_2Cl_2 maintained at 0 °C. The resulting mixture was stirred for an additional hour and then warmed to room temperature, where it was maintained for 3 h, after which time it was filtered through a sand plug and then Celite. The filtrate was concentrated under reduced pressure to provide crude succinimidyl diazoacetate as a brown-yellow solid. Recrystallization from CH_2Cl_2/hexanes gave light yellow crystalline product (43.0 g, 0.235 mmol, 47% yield): mp 113.5−115.0 °C (lit.[6] mp 119−120 °C); ^{1}H NMR δ 5.13 (br s, 1 H), 2.85 (s, 4 H).

General Procedure for the Preparation of *N*-Allylic-*N*-methylamines.[5] To a stirred suspension of KH (35 wt % in mineral oil; 6.86 g, 60.0 mmol) in 250 mL of absolute ether under a nitrogen atmosphere was added a solution of *N*-methyltrifluoroacetamide (6.35 g, 50.0 mmol) and 0.13 g (0.50 mmol) of 18-crown-6 in 75 mL of anhydrous ether dropwise over 30 min. After the mixture was stirred for an additional hour, the allyl bromide (70.0 mmol) was added dropwise over 30 min, and the resulting mixture was refluxed with vigorous stirring for 24 h. Cautious acidification was performed by adding 10% aqueous HCl at 0 °C, the organic layer was separated, and solvent was removed under reduced pressure. The crude *N*-allyl-*N*-methyl trifluoroacetamide was then treated with a solution of KOH (4.20 g, 75.0 mmol) in 100 mL of 1:1 MeOH:H_2O and stirred for 3 h at 25 °C. After acidification with concd HCl at 0 °C, methanol was removed under reduced pressure, and the resulting aqueous solution was washed twice with 50-mL portions of ether. The amine hydrochloride in water was combined with 50 mL of ether, and the free amine was generated by the addition of KOH pellets at 0 °C. The etheral solution of the amine was separated and dried over KOH, and the solvent was removed by distillation at atmospheric pressure. The residue was distilled under vacuum to provide the pure amine as a colorless liquid. ***N*-Methyl-*N*-(3-methyl-2-buten-1-yl)amine (7a),**[17] bp 116−118 °C, was prepared in 61% yield: ^{1}H NMR δ 5.29−5.21 (m, 1 H), 3.16 (d, J = 6.9 Hz, 2 H), 2.41 (s, 3 H), 1.72 (br s, 3 H), 1.65 (s, 3 H), 1.10 (br s, 1 H). ***N*-(*trans*-3,7-Dimethyl-2,6-octadien-1-yl)-*N*-methylamine (7d),**[18] bp 124−126 °C (25 Torr), was prepared in 90% yield: ^{1}H NMR δ 5.29−5.21 (m, 1 H), 5.14−5.06 (m, 1 H), 3.18 (d, J = 6.7 Hz, 2 H), 2.42 (s, 3 H), 2.15−1.97 (comp, 4 H), 1.68 (s, 3 H), 1.65 (s, 3 H), 1.60 (s, 3 H), 1.31 (s, 1 H).

***N*-(*trans*-2-Hexen-1-yl)-*N*-methylamine (7b)**: bp 81−84 °C (105 Torr), prepared in 59% yield; ^{1}H NMR δ 5.65−5.45 (comp, 2 H), 3.16−3.13 (comp, 2 H), 2.41 (s, 3 H), 2.04−1.96 (comp, 2 H), 1.39 (hex, J = 7.4 Hz, 2 H), 1.11 (br s, 1 H), 0.90 (t, J = 7.3 Hz, 3 H); ^{13}C NMR δ 132.5, 128.2, 53.7, 35.7, 34.4, 22.4, 13.5; IR (film) 3289 (br, NH), 2959, 2928, 2873, 2843, 2788, 1669 (C=C) cm^{-1}. Anal. Calcd for $C_7H_{15}N$: C, 74.27; H, 13.36; N, 12.38. Found: C, 74.18; H, 13.23; N, 12.31.

***N*-(*cis*-2-Hexen-1-yl)-*N*-methylamine (7c)**: bp 81−84 °C (105 Torr), prepared in 67% yield; ^{1}H NMR δ 5.56−5.41 (comp, 2 H), 3.25−3.21 (comp, 2 H), 2.43 (s, 3 H), 2.08−2.00 (comp, 2 H), 1.39 (hex, J = 7.1 Hz, 2 H), 1.12 (br s, 1 H), 0.91 (t, J = 7.3 Hz, 3 H); ^{13}C NMR δ 131.8, 127.8, 48.1, 35.8, 29.3, 22.6, 13.5; IR (film) 3291 (br, NH), 3012, 2960, 2931, 2872, 2845, 2786, 1655 (C=C) cm^{-1}. Anal. Calcd for $C_7H_{15}N$: C, 74.27; H, 13.36; N, 12.38. Found: C, 74.26; H, 13.28; N, 12.24.

General Procedure for the Preparation of *N*-Allylic-*N*-methyldiazoacetamides. To an ice-bath cooled solution of the *N*-allylic-*N*-methylamine (9.6 mmol) and triethylamine (1.21 g, 12.0 mmol) in 20 mL of anhydrous CH_2Cl_2 was added over 10 min a solution of succinimidyl diazoacetate (1.46 g, 7.98 mmol) in 30 mL of the same solvent. The mixture was stirred for 30 min at 0 °C and then for 1 h at room temperature. After concentration of the solution under vacuum, the residue was purified by flash chromatography on silica gel (1:1 hexanes:EtOAc) to yield the yellow diazoacetamide. All operations were conducted at or below room temperature, and the diazoacetamides were stired in a refrigerator. NMR spectra revealed significant broadening of absorptions for atoms near nitrogen, suggesting restricted rotation.

***N*-Methyl-*N*-(3-methyl-2-buten-1-yl)diazoacetamide (7a)**: prepared in 81% yield; R_f = 0.46 (1:1 hexanes:EtOAc); ^{1}H NMR δ 5.15−5.08 (m, 1 H), 4.94 (s, 1 H), 4.00−3.75 (br m, 2 H), 2.84 (br s, 3 H), 1.74 (s, 3 H), 1.69 (s, 3 H); ^{13}C NMR δ 165.3, 135.9, 119.4, 46.0, 46.0, 33.5, 25.4, 17.5; IR (film) 2102 (C=N_2), 1618 (C=O) cm^{-1}. Anal. Calcd for $C_8H_{13}N_3O$: C, 57.46; H, 7.83; N, 25.13. Found: C, 57.41; H, 7.89; N, 25.03.

***N*-(*trans*-2-Hexen-1-yl)-*N*-methyldiazoacetamide (7b)**: prepared in 86% yield; R_f = 0.51 (1:1 hexanes:EtOAc); ^{1}H NMR δ 5.64−5.53 (m, 1 H), 5.41−5.30 (m, 1 H), 4.95 (s, 1 H), 4.00−3.60 (br m, 2 H), 3.00−2.70 (br s, 3 H), 2.07−1.98 (comp, 2 H), 1.40 (hex, J = 7.3 Hz, 2 H), 0.89 (t, J = 7.3 Hz, 3 H); ^{13}C NMR δ 165.6, 133.9, 124.3, 50.3 (br), 46.1, 34.1, 33.6, 22.1, 13.4; IR (film) 2100 (C=N_2), 1605 (C=O) cm^{-1}. Anal. Calcd for $C_9H_{15}N_3O$: C, 59.64; H, 8.34; N, 23.18. Found: C, 59.56; H, 8.39; N, 23.12.

***N*-(*cis*-2-Hexen-1-yl)-*N*-methyldiazoacetamide (7c)**: prepared in 82% yield; R_f = 0.55 (1:1 hexanes:EtOAc); ^{1}H NMR δ 5.66−5.55 (m, 1 H), 5.38−5.28 (m, 1 H), 4.95 (s, 1 H), 4.10−3.80 (br m, 2 H), 2.95−2.80 (br s, 3 H), 2.12−2.04 (comp, 2 H), 1.42 (hex, J = 7.3 Hz, 2 H), 0.93 (t, J = 7.3 Hz, 3 H); ^{13}C NMR δ 165.1, 133.2, 124.2, 45.8 (br), 45.6, 33.1, 28.8, 22.2, 13.1; IR (film) 2104 (C=N_2), 1603 (C=O) cm^{-1}. Anal. Calcd for $C_9H_{15}N_3O$: C, 59.64; H, 8.34; N, 23.18. Found: C, 59.52; H, 8.38; N, 23.10.

***N*-(*trans*-3,7-Dimethyl-2,6-dien-1-yl)-*N*-methyldiazoacetamide (7d)**: prepared in 93% yield; R_f = 0.74 (1:1 hexanes:EtOAc); ^{1}H NMR δ 5.14−5.02 (comp, 2 H), 4.95 (s, 1 H), 4.05−3.70 (br m, 2 H), 2.92−2.77 (br s, 3 H), 2.15−1.98 (comp, 4 H), 1.68 (s, 6 H), 1.60 (s, 3 H); ^{13}C NMR δ 165.2, 139.3, 131.3, 123.5, 119.2, 45.9, 45.8 (br), 39.2, 33.3, 26.0, 25.3, 17.3, 15.8; IR (film) 2103 (C=N_2), 1608 (C=O) cm^{-1}. Anal. Calcd for $C_{13}H_{21}N_3O$: C, 66.35; H, 8.99; N, 17.86. Found: C, 66.21; H, 9.07; N, 17.73.

***N*-Methyl-*N*-(2-propen-1-yl)diazoacetamide (8)**: prepared in 84% yield; R_f = 0.35 (1:1 hexanes:EtOAc); thermally unstable and used immediately after chromatography; ^{1}H NMR δ 5.80−5.66 (m, 1 H), 5.21−5.10 (comp, 2 H), 4.95 (s, 1 H), 4.10−3.60 (br m, 2 H), 2.86 (br s, 3 H); ^{13}C NMR δ 165.0, 131.9, 115.9, 49.9 (br), 45.3, 33.1; IR (film) 2104 (C=N_2), 1607 (C=O) cm^{-1}.

3,3α,4,5,6,6α-Hexahydro-5-methylpyrrolo[3,4-*c*]pyrazol-6-one (10). A solution of 0.139 g (1.00 mmol) of **8** in 5 mL of $CHCl_3$ was refluxed for 2.5 h. After evaporation of the solvent, **10** was obtained in quantitative yield as a colorless oil: ^{1}H NMR δ 5.50 (dddd, J = 9.2, 3.3, 1.6, 0.8 Hz, 1 H), 4.84 (ddd, J = 18.4, 9.2, 1.6 Hz, 1 H), 4.60 (ddd, J = 18.4, 3.3, 2.3 Hz, 1 H), 3.65 (dd, J = 10.5, 8.6 Hz, 1 H), 2.98 (dd, J = 10.5, 3.4 Hz, 1 H), 2.91−2.79 (m, 1 H), 2.82 (s, 3 H); ^{13}C NMR δ 165.8, 95.5, 85.2, 53.9, 28.9, 26.0; IR (film) 1678 (C=O) cm^{-1}. Anal. Calcd for $C_6H_9N_3O$: C, 51.79; H, 6.52; N, 30.19. Found: C, 51.86; H, 6.41; N, 30.27.

***N*-Ethyl-*N*-(2-methyl-2-propen-1-yl)diazoacetamide (15)**: prepared in 91% yield; R_f = 0.26 (3:1 hexanes:EtOAc); ^{1}H NMR δ 4.93 (br s, 1 H), 4.90 (s, 1 H), 4.82 (s, 1 H), 4.00−3.50 (br m, 2 H), 3.50−3.20 (br m, 2 H), 1.71 (s, 3 H), 1.14 (t,

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J = 7.1 Hz, 3 H); ^{13}C NMR δ 165.5, 140.5 (br), 111.7 (br), 51.8 (br), 46.2, 41.3, 19.7, 13.1; IR (film) 2111 (C═N_2), 1609 (C═O) cm^{-1}. Anal. Calcd for $C_8H_{13}N_3O$: C, 57.47; H, 7.83; N, 25.13. Found: C, 57.56; H, 7.81; N, 25.07.

Catalytic Cyclopropanation of *N*-Allylic-*N*-methyldiazoacetamides. General Procedure. A solution of the diazoacetamide (1.00 mmol) in 10 mL of anhydrous CH_2Cl_2 was added via syringe pump over 10 h (1.0 mL/h) to a solution of the catalyst (0.1−1.0 mol %) in 10 mL of CH_2Cl_2. (With **8** a 5 h addition time was employed.) After addition was complete, the reaction solution was filtered through a silica gel plug to remove the dirhodium(II) catalysts, and the solvent was then evaporated under reduced pressure. Analyses by GC and NMR were performed on the residue before distillation or chromatographic purification.

(1*R*,5*S*)-3-Methyl-3-azabicyclo[3.1.0]hexan-2-one (9): colorless oil, bp 70−75 °C (0.2 Torr); enantiomer separation on a 30-m Chiraldex G-TA column operated at 140 °C, 11.2 min for the major isomer, (1*R*,5*S*)-**9**, and 14.6 min for the minor isomer, (1*S*,5*R*)-**9**, from reaction catalyzed by Rh_2(5(*S*)-MEPY)$_4$: $[\alpha]^{20}_D$ = +59.9 (*c* 2.95, $CHCl_3$) for 93% ee; ^{1}H NMR δ 3.52 (dd, J = 10.3, 5.7 Hz, 1 H), 3.28 (dd, J = 10.3, 1.8 Hz, 1 H), 2.74 (s, 3 H), 1.94−1.79 (comp, 2 H), 1.09 (ddd, J = 8.0, 8.0, 4.5 Hz, 1 H), 0.59 (ddd, J = 4.5, 4.5, 3.2 Hz, 1 H); ^{13}C NMR δ 175.1, 51.4, 29.2, 20.2, 12.8, 11.8; IR (film) 1679 (C═O) cm^{-1}; mass spectrum, *m*/*z* (rel abundance) 112 (8, M + 1), 111 (100, M), 110 (39, M − 1), 96 (15), 83 (19), 82 (35), 68 (37), 55 (52), 54 (37), 53 (22). Anal. Calcd for C_6H_9NO: C, 64.80; H, 8.16; N, 12.60. Found: C, 64.80; H, 8.10; N, 12.56.

Treatment of (1*R*,5*S*)-3-azabicyclo[3.1.0]hexan-2-one[4] with MeI (NaH/THF, 25 °C; 92% yield) produced **9** whose specific rotation and chromatographic analysis confirmed the absolute configuration of the product from Rh_2(5(*S*)-MEPY)$_4$-catalyzed diazo decomposition of **8** as (1*R*,5*S*)-**9**: $[\alpha]^{20}_D$ = +49.0 (*c* 1.08, $CHCl_3$) for 93% ee.

(1*S*,5*R*)-3,6,6-Trimethyl-3-azabicyclo[3.1.0]hexan-2-one (11a): colorless oil, bp 75−80 °C (0.4 Torr); chromatographic purification with 1:4 hexanes:EtOAc; enantiomer separation on a 30-m Chiraldex G-TA column operated at 130 °C, 23.0 min for the minor isomer, (1*R*,5*S*)-**11a**, and 25.3 min for the major isomer, (1*S*,5*R*)-**11a**, from reactions with Rh_2(4(*S*)-MEOX)$_4$ (94% ee): $[\alpha]^{21}_D$ = +100.4 (*c* 2.78, $CHCl_3$) for 94% ee; ^{1}H NMR δ 3.52 (dd, J = 10.9, 6.6 Hz, 1 H), 3.10 (d, J = 10.9 Hz, 1 H), 2.73 (s, 3 H), 1.79 (dd, J = 6.6, 1.8 Hz, 1 H), 1.60 (t, J = 6.6 Hz, 1 H), 1.10 (s, 3 H), 0.99 (s, 3 H); ^{13}C NMR δ 172.7, 48.2, 33.1, 28.5, 25.6, 23.9, 21.5, 13.7; IR (film) 1667 (C═O) cm^{-1}; mass spectrum, *m*/*z* (rel abundance) 140 (16 M + 1), 139 (99, M), 138 (18, M − 1), 124 (36), 111 (25), 98 (97), 97 (34), 96 (60), 83 (24), 82 (100), 81 (77), 68 (69), 67 (100), 55 (48), 54 (44), 53 (66). Anal. Calcd for $C_8H_{13}NO$: C, 69.03; H, 9.41; N, 10.06. Found: C, 68.95; H, 9.31; N, 9.98.

1-Methyl-1-(2-methylethyl)-1,5-dihydro-2*H*-pyrrol-2-one (12a) was isolated by column chromatography on silica gel (1:4 EtOAc:hexanes) as a colorless oil: ^{1}H NMR δ 5.83−5.81 (m, 1 H), 3.88 (s, 2 H), 3.01 (s, 3 H), 2.62 (d hept, J = 1.4, 7.0 Hz, 1 H), 1.17 (d, J = 7.0 Hz, 6 H); ^{13}C NMR δ 172.3, 165.1, 120.4, 55.0, 29.03, 28.98, 21.5; IR (film) 1670 (C═O) cm^{-1}; mass spectrum, *m*/*z* (rel abundance) 140 (4, M + 1), 139 (36, M), 138 (4, M − 1), 124 (60), 97 (59), 96 (100), 81 (12), 67 (17), 53 (19).

[1*R*-(1α,5α,6*β*)]-6-*n*-Propyl-3-azabicyclo[3.1.0]hexan-2-one (11b): colorless oil, bp 80−85 °C (0.15 Torr); chromatographic purification with 1:2 hexanes:EtOAc; enantiomer separation on a 30-m Chiraldex G-TA column operated at 135 °C, 22.2 min for the major isomer, (1*R*)-**11b**, and 28.2 min for the minor isomer, (1*S*)-**11b**, from reaction with Rh_2(4(*S*)-MPPIM)$_4$: $[\alpha]^{20}_D$ = +57.4 (*c* 1.99, $CHCl_3$) for 92% ee; ^{1}H NMR δ 3.48 (dd, J = 10.3, 5.9 Hz, 1 H), 3.27 (dd, J = 10.3, 1.5 Hz, 1 H), 2.72 (s, 3 H), 1.69 (dt, J = 6.2, 2.1 Hz, 1 H), 1.60 (dt, J = 6.2, 3.6 Hz, 1 H), 1.51−1.17 (comp, 4 H), 0.93 (t, J = 7.0 Hz, 3 H); ^{13}C NMR δ 174.5, 51.4, 33.5, 29.1, 26.9, 26.4, 21.9, 18.3, 13.7; IR (film) 1685 (C═O) cm^{-1}; mass spectrum, *m*/*z* (rel abundance) 154 (15, M + 1), 153 (98, M), 152 (18, M − 1), 138 (22), 124 (32), 111 (70), 110 (96), 99 (44), 98 (89), 97 (47), 96 (94), 82 (47), 81 (100), 69 (54), 68 (92), 67 (100), 55 (89), 55 (100), 53 (91). Anal. Calcd for $C_9H_{15}NO$: C, 70.55; H, 9.87; N, 9.14. Found: C, 70.51; H, 9.82; N, 9.21.

1-Methyl-4-*n*-butyl-1,5-dihydro-2*H*-pyrrol-2-one (12b = 12c) was isolated by column chromatography on silica gel (2:1 EtOAc:hexanes, R_f = 0.27) as a colorless oil: ^{1}H NMR (C_6D_6) δ 5.74 (quin, J = 1.5 Hz, 1 H), 2.87−2.85 (m, 2 H), 2.63 (s, 3 H), 1.73−1.67 (comp, 2 H), 1.10−1.00 (comp, 4 H), 0.75 (t, J = 7.0 Hz, 3 H); ^{13}C NMR (C_6D_6) δ 171.2, 158.2, 122.5, 55.4, 29.8, 29.1, 28.4, 22.5, 13.8; IR (film) 1677 (C═O) cm^{-1}; mass spectrum, *m*/*z* (rel abundance) 154 (7, M + 1), 153 (61, M), 111 (23), 110 (100), 97 (32), 96 (95), 82 (32), 68 (24), 67 (23), 55 (30).

[1*R*-(1α,5α,6α)]-6-*n*-Propyl-3-azabicyclo[3.1.0]hexan-2-one (11c): colorless oil, bp 80−90 °C (0.1 Torr); chromatographic purification with 1:2 hexanes:EtOAc; enantiomer separation on a 30-m Chiraldex G-TA column operated at 135 °C, 24.5 min for the major isomer, (1*R*)-**11c**, and 28.3 min for the minor isomer, (1*S*)-**11c**, from reaction with Rh_2(4(*S*)-MPPIM)$_4$: $[\alpha]^{20}_D$ = +78.6 (*c* 1.51, $CHCl_3$) for 95% ee; ^{1}H NMR δ 3.54 (dd, J = 10.9, 6.5 Hz, 1 H), 3.11 (d, J = 10.9 Hz, 1 H), 2.74 (s, 3 H), 2.06−1.99 (m, 1 H), 1.83 (q, J = 6.5 Hz, 1 H), 1.54−1.38 (comp, 2 H), 1.26−1.12 (comp, 3 H), 0.95 (t, J = 7.4 Hz, 3 H); ^{13}C NMR δ 172.5, 47.4, 28.2, 24.9, 24.2, 22.0, 21.1, 16.0, 13.7; IR (film) 1685 (C═O) cm^{-1}; mass spectrum, *m*/*z* (rel abundance) 154 (5, M + 1), 153 (31, M), 152 (7, M − 1), 138 (10), 124 (15), 111 (17), 110 (100), 98 (86), 97 (62), 96 (39), 82 (32), 81 (91), 69 (38), 68 (63), 67 (76), 55 (64), 54 (94), 53 (77). Anal. Calcd for $C_9H_{15}NO$: C, 70.55; H, 9.87; N, 9.14. Found: C, 70.46; H, 9.81; N, 9.12.

[1*S*-(1α,5α)]-6α-Methyl-6*β*-(4-methyl-3-penten-1-yl)-3-azabicyclo[3.1.0]hexan-3-one (11d): colorless oil, bp 120−125 °C (0.25 Torr); chromatographic purification with 1:2 hexanes:EtOAc; enantiomer separation on a 30-m Chiraldex G-TA column operated at 140 °C, 94.1 min for the major ismoer, (1*S*)-**11d**, and 98.8 min for the minor isomer, (1*R*)-**11d**, from reaction with Rh_2(4(*S*)-MEOX)$_4$: $[\alpha]^{20}_D$ = +66.1 (*c* 2.41, $CHCl_3$) for 94.5% ee; ^{1}H NMR δ 5.10−5.02 (m, 1 H), 3.53 (dd, J = 11.0, 6.6 Hz, 1 H), 3.08 (d, J = 11.0 Hz, 1 H), 2.73 (s, 3 H), 2.15−2.00 (comp, 2 H), 1.80 (dd, J = 6.6, 1.8 H, 1 H), 1.67 (s, 3 H), 1.60 (s, 3 H), 1.38−1.14 (comp, 2 H), 0.97 (s, 3 H); ^{13}C NMR δ 172.7, 131.7, 123.7, 48.1, 39.7, 32.3, 28.5, 25.6, 25.6, 24.9, 23.2, 17.5, 11.0; IR (film) 1686 (C═O) cm^{-1}; mass spectrum, *m*/*z* (rel abundance) 208 (9, M + 1), 207 (48 M), 192 (13), 164 (29), 151 (17), 138 (56), 125 (51), 124 (82), 110 (56), 99 (46), 98 (100) 95 (47), 82 (45), 81 (53), 79 (62), 69 (100), 67 (85), 53 (83). Anal. Calcd for $C_{13}H_{21}NO$: C, 75.31; H, 10.21; N, 6.76. Found: C, 75.25; H, 10.13; N, 6.68.

1-Methyl-4-(6-methyl-5-hepten-2-yl)-1,5-dihydro-2*H*-pyrrol-2-one (12d) was isolated by column chromatography on silica gel (2:1 EtOAc:hexanes) as a colorless oil: ^{1}H NMR (C_6D_6) δ 5.78 (q, J = 1.4 Hz, 1 H), 5.04 (t hept, J = 7.1, 1.4 Hz, 1 H), 3.00−2.98 (m, 2 H), 2.63 (s, 3 H), 2.03 (hex, J = 7.0 Hz, 1 H), 1.82 (q, J = 7.3 Hz, 2 H), 1.66 (q, J = 1.4 Hz, 3 H), 1.49 (d, J = 0.9 Hz, 3 H), 1.30−1.05 (comp, 2 H), 0.74 (d, J = 7.0 Hz, 3 H); ^{13}C NMR (C_6D_6) δ 171.0, 162.9, 131.8, 124.3, 121.9, 53.8, 35.9, 33.8, 28.4, 25.82, 25.78, 19.3, 17.7; IR (film) 1683 (C═O), 1621 (C═C) cm^{-1}; mass spectrum, *m*/*z* (rel abundance) 208 (4, M + 1), 207 (17, M), 192 (9), 164 (11), 150 (25), 138 (32), 125 (52), 124 (100), 110 (26), 94 (18), 69 (24), 55 (22), 53 (23).

(1*R*,5*S*)-3-Ethyl-5-methyl-3-azabicyclo[3.1.0]hexan-2-one (16): colorless oil, bp 72−75 °C (0.15 Torr); chromatographic purification with 1:2 hexanes:EtOAc; enantiomer separation on a 30-m Chiraldex B-PH column operated at 90 °C, 76.9 min for the major isomer, (1*R*,5*S*)-**16**, and 84.2 min for the minor isomer (1*S*,5*R*)-**16**, from reaction with Rh_2(4(*S*)-MACIM)$_4$: $[\alpha]^{20}_D$ = −5.1 (*c* 3.13, $CHCl_3$) for 48% ee; ^{1}H NMR δ 3.35−3.11 (comp, 4 H), 1.67 (ddd, J = 8.5, 3.2, 1.7 Hz, 1 H), 1.33 (s, 3 H), 1.05 (t, J = 7.2 Hz, 3 H), 0.99 (dd, J = 8.5, 4.4 Hz, 1 H), 0.69 (dd, J = 4.4, 3.2 Hz, 1 H); ^{13}C NMR δ 175.2, 53.6, 36.6, 27.0, 19.6, 19.1, 19.0, 12.7; IR (film) 1673 (C═O) cm^{-1}; mass spectrum, *m*/*e* (rel abundance) 140 (7, M + 1), 139 (75, M), 138 (9, M − 1), 124 (89), 111 (25), 96 (100), 95 (30), 68 (63), 67 (72), 55 (77), 53 (46). Anal. Calcd for $C_8H_{13}NO$: C, 69.03; H, 9.41; N, 10.06. Found: C, 69.10; H, 9.51; N, 9.97.

1-(2-Methyl-2-propen-1-yl)pyrrolidin-2-one (17) was identified from its NMR spectra: ^{1}H NMR δ 4.89−4.84 (m, 1 H), 4.80−4.77 (m, 1 H), 3.80 (br s, 2 H), 3.28 (t, J = 7.0 Hz, 2 H), 2.41 (t, J = 7.9 Hz, 2 H), 2.07−1.95 (comp, 2 H), 1.63 (s, 3 H); ^{13}C NMR δ 174.8, 140.0, 112.5, 48.5, 46.6, 30.8, 19.8, 17.7. The ^{1}H NMR spectrum was identical to that reported in the literature for this compound.[19]

1-Ethyl-5-methyl-5,6-dihydro-2-piperidone (18). Isolated by column chromatography on silica gel (2:1 EtOAc:hexanes) as a colorless oil. ^{1}H NMR δ 6.38 (dd, J = 9.8, 3.4 Hz, 1 H), 5.86 (dd, J = 9.8, 1.9 Hz, 1 H), 3.58−3.32 (comp, 3 H), 3.12 (dd, J = 12.2, 8.5 Hz, 1 H), 2.68−2.53 (m, 1 H), 1.14 (t, J = 7.1 Hz, 3 H), 1.11 (d, J = 6.9 Hz, 3 H); ^{13}C NMR δ 163.9, 144.8, 124.5, 51.7, 41.3, 29.4, 17.4, 12.5; IR (film) 1672 (C=O) cm^{-1}; mass spectrum, m/z (rel abundance) 140 (4, M + 1), 139 (50, M), 138 (4, M − 1), 124 (47), 110 (10), 95 (32), 82 (100), 81 (33), 67 (23), 58 (25), 54 (48), 53 (25).

(19) Voshchula, V. N.; Tolkunov, S. V.; Zubritskii, M. Yu.; Dulenko, V. I. *Chem. Heterocycl. Compds.* **1988**, *24*, 1175.

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Supporting Information Available: Copies of spectra for **12a**−**12d** and **18** (8 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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