A Novel Cycloaddition Reaction of α-Diazo-γ-amido Ketones Catalyzed by Rhodium(II) Acetate. Scope and Mechanistic Details of the Process†

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α-Diazo ketones containing an amido group in the γ-position have been found to undergo a novel rhodium(II)-catalyzed cycloaddition reaction. Intramolecular cyclization of the keto carbenoid onto the oxygen atom of the amide group generates a carbonyl ylide dipole as a transient species. This highly stabilized dipole does not readily undergo 1,3-dipolar cycloaddition but rather transfers a proton to produce a cyclic ketene *N*,*O*-acetal. The ketene acetal is unstable to moisture and upon standing is readily hydrolyzed to a γ-keto δ-lactone and an amine. In the absence of any significant amount of water, the ketene *N*,*O*-acetal undergoes conjugate addition with the activated π-bond of the dipolarophile to give a zwitterion intermediate. The anionic portion of the zwitterion adds to the neighboring carbonyl group. This is followed by epoxide ring formation with charge dissipation leading to an amido-substituted spiro cyclopentyl epoxide. In certain cases a hydroxy lactone was also isolated and its formation can be attributed to the competitive hydrolysis of the zwitterionic intermediate. The Rh(II)-catalyzed reaction of the diazo ketoamide derived from *N*-benzylpiperidone with DMAD afforded two different types of cycloadducts. In addition to the spiro cyclopentyl epoxide, a product derived from trapping of the carbonyl ylide dipole was also obtained, thereby providing additional support for the proposed mechanism.

The development of methods that efficiently construct polyazacyclic, multifunctional systems by tandem processes[1−4] is of great interest in synthetic chemistry. Sequential methods for synthesis are particularly attractive because complex products may be accessed in a single, one-pot process from relatively simple precursors.[5] Tandem cationic,[6−10] anionic,[11−18] radical,[19−23] pericyclic[24−28] and transition metal catalyzed processes[29−36] have been featured in the synthesis of important natural products over the past two decades. Recent papers from these laboratories have described a route to polycyclic ring systems which involves the tandem cyclization−cycloaddition of a transient rhodium carbenoid.[37] As indicated in Scheme 1, a cyclic carbonyl ylide intermediate (**2**) is generated by treatment of a diazoalkanedione (**1**) with rhodium(II) carboxylates. The success of the method relies on intramolecular attack of the neighboring carbonyl oxygen at the rhodium carbenoid center to form the 1,3-dipole which subsequently cycloadds across a π-bond.

As part of a program aimed at developing new cascade methodology and achieving various total syntheses of nitrogen-containing heterocycles employing this reaction, we have been systematically investigating the process.

† This paper is dedicated to Professor Norman A. Lebel on the occasion of his 65th birthday..

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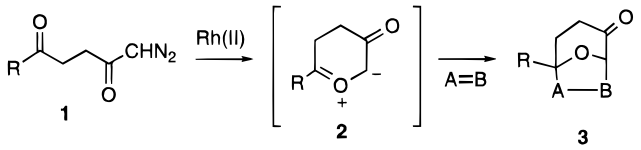
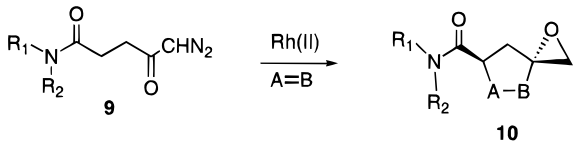
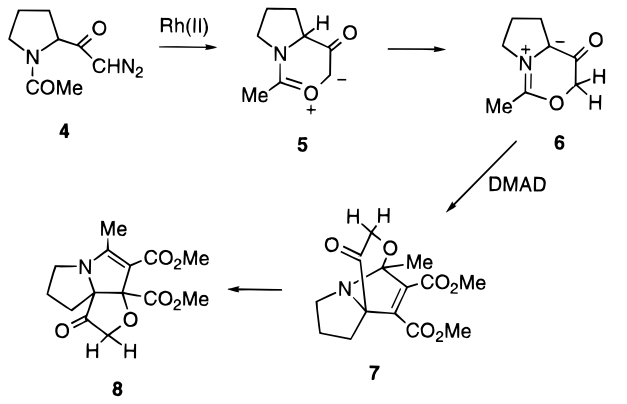
Scheme 1



Scheme 2



Some of our more recent methodological achievements in this area involve the use of diazo ketoamides.[38] The ensuing studies showed that the nature of the interacting carbonyl group can significantly affect the course of the tandem cycloaddition process. As a specific illustration, 1-acetyl-2-(1-diazoacetyl)pyrrolidine (**4**) was observed to react with DMAD in the presence of a Rh(II) catalyst to

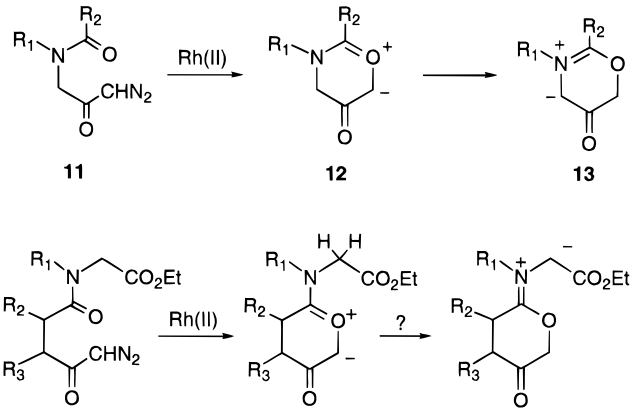


give the rearranged cycloadduct **8**.[39,40] The mechanism proposed to rationalize the formation of this novel product involves generation of the expected carbonyl ylide dipole **5** by intramolecular cyclization of the keto carbenoid onto the oxygen atom of the amide group. Isomerization of **5** to the thermodynamically more stable azomethine ylide **6** occurs *via* proton exchange with a small amount of water that was present in the reaction mixture. 1,3-Dipolar cycloaddition with DMAD provides cycloadduct **7**, which undergoes a subsequent 1,3-alkoxy shift to generate the tricyclic dihydropyrrolizine **8**. The overall reaction has been termed a "dipole cascade" since it involves the interconversion of three distinct classes of 1,3-dipoles.[39]

To further demonstrate the synthetic potential of the *amido cascade process*, experiments involving a series of related diazo ketoamides were carried out.[41] In this paper we present full details of our initial discovery and development of a new class of bimolecular cycloaddition of diazo ketoamides.[41] This new tandem cycloaddition process is generically outlined in Scheme 2. The reaction takes place with both olefinic and acetylenic dipolarophiles to give spiro amido cyclopentyl epoxides of type **10** and occurs in several discrete stages. In order to explore this novel process in more detail, several α-diazo-γ′-amido ketones were synthesized and treated with a rhodium(II) catalyst. The results of these studies are reported herein.

Results and Discussion

The discovery of the *dipole cascade process* in our laboratory[39] which interconverts α-diazo ketones **11** to azomethine ylides **13** *via* the intermediacy of carbonyl ylides **12** prompted us to explore the generality of this transformation using the related α-diazo keto amides **14** and/or **17**. Mopac (PM3) calculations show that cyclic



azomethine ylides of type **13** are generally *ca.* 15 kcal/mol lower in their heat of formation than the corresponding carbonyl ylides **12**. Some of this energy difference is presumably responsible for the facility with which the dipole reorganization occurs. Within this context, we studied the rhodium(II)-catalyzed behavior of α-diazoketo amide **14**. In this case the carbonyl ylide dipole **15** was trapped by dimethyl acetylenedicarboxylate (DMAD) to

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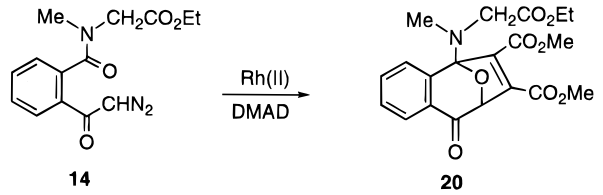
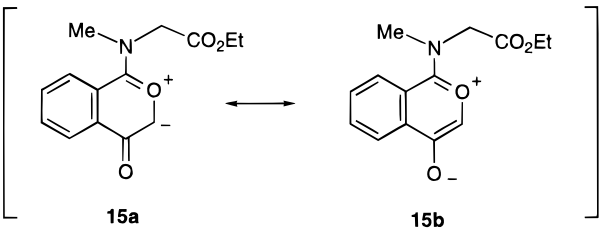
give cycloadduct **20** in 90% yield. No signs of any



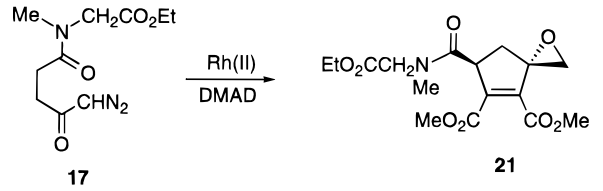
14 **20**

material derived from azomethine ylide **16** could be detected in the crude reaction mixture. The PM3 calculations[42] indicate that the carbonyl ylide dipole derived from **14** (*i.e.*, **15**) has a heat of formation (−69.6 kcal/mol) that is 7.5 kcal less than that of the corresponding azomethine ylide **16** (−62.1 kcal/mol). More than likely the aromatic nature of the benzopyrylium oxide dipole **15** accounts for its enhanced stability relative to azomethine ylide **16** and its reluctance to undergo a proton shift.



15a **15b**

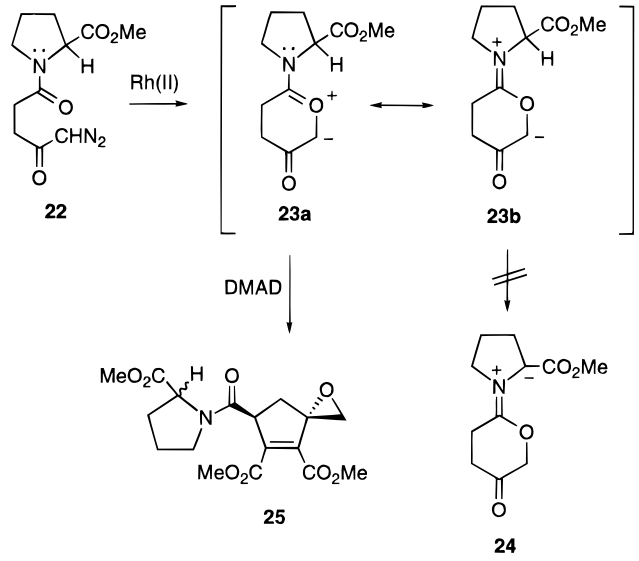
Subjection of the closely related α-diazo ketoamide **17** to the Rh(II)-catalyzed conditions was next carried out. Our first expectation was that the initially formed carbonyl ylide intermediate **18** would undergo proton transfer to give the thermodynamically more stable azomethine ylide dipole **19**. Ampac calculations show that carbonyl ylide **18** (R_1 = CH_3) (−94.93 kcal) is 19 kcal less stable than azomethine ylide **19** (−113.95 kcal) which fits the pattern previously encountered in the *dipole cascade process*. We found, however, that treatment of **17** with DMAD and a catalytic amount of rhodium(II) acetate resulted in the isolation of the totally unexpected cycloadduct **21** in 60% yield. The struc-



17 **21**

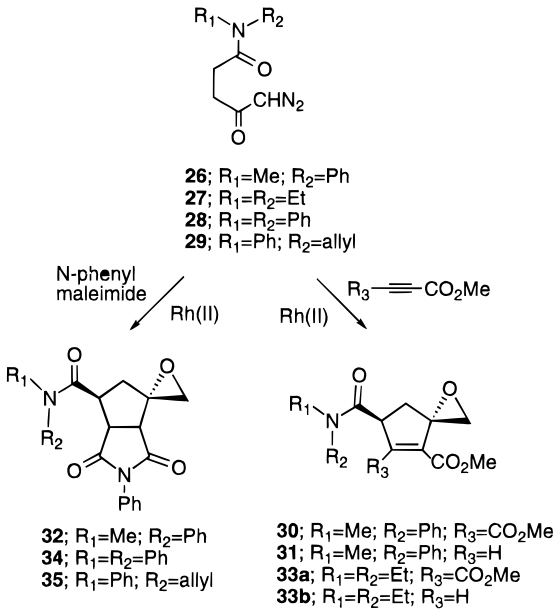
ture of **21** was assigned on the basis of its spectral properties, in particular, the ^{1}H-NMR spectrum which showed the methyl groups as three distinct singlets at 3.19, 3.76 and 3.78, the epoxy hydrogens as doublets at 3.06 (J = 4.1 Hz) and 3.37, an AB pattern at 4.10 (J = 17.1 Hz) and 4.23 (J = 17.1 Hz), an ABX pattern at 2.28 (dd, 1H, J = 14.0 and 9.0 Hz), 2.45 (dd, 1H, J = 14.0 and 6.0 Hz), and 4.54 (dd, 1H, J = 9.0 and 6.0 Hz) and a set of hydrogens attributable to the ethyl group.

An additional attempt to induce the *dipole cascade rearrangement* using the carbomethoxy-substituted diazopyrrolidine pentanedione **22** also failed to give any cycloadduct derived from an azomethine ylide intermediate (*i.e.*, **24**). Instead, the Rh(II)-catalyzed reaction of **22** in the presence of DMAD afforded the unusual rearrangement−cycloaddition product **25** as a 2:1 mixture of diastereomers.[43]



22 **23a** **23b** **25** **24**

Similar results were obtained when diazo keto *N*-phenyl-*N*-methylamide **26** was used. Treatment of this compound with rhodium(II) acetate in the presence of DMAD, methyl propiolate, or *N*-phenylmaleimide afforded cycloadducts **30** (60%), **31** (55%), and **32** (70%). Analogous cycloadducts were also obtained when diazo keto *N*,*N*-diethylamide (**27**), the related *N*,*N*-diphenylamide (**28**), and *N*-phenyl-*N*-allylamide (**29**) were used.



26; R_1=Me; R_2=Ph
27; R_1=R_2=Et
28; R_1=R_2=Ph
29; R_1=Ph; R_2=allyl

32; R_1=Me; R_2=Ph
34; R_1=R_2=Ph
35; R_1=Ph; R_2=allyl

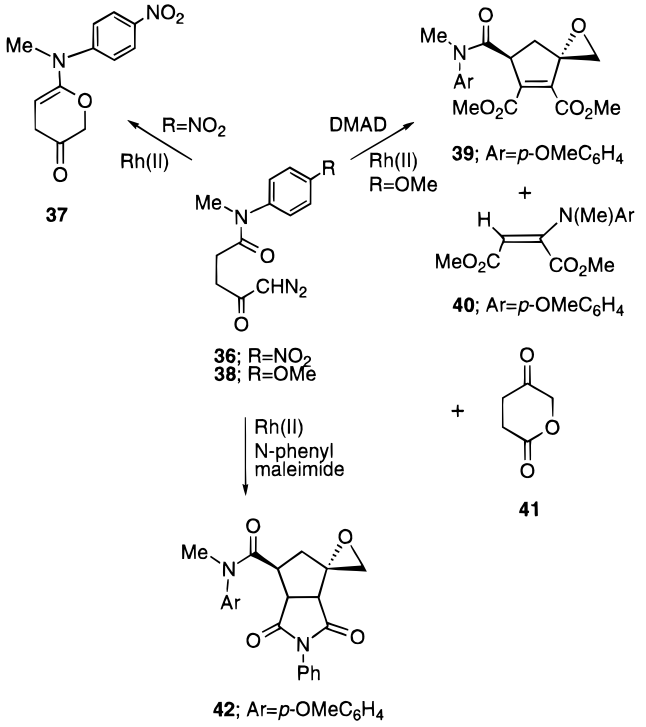
30; R_1=Me; R_2=Ph; R_3=CO_2Me
31; R_1=Me; R_2=Ph; R_3=H
33a; R_1=R_2=Et; R_3=CO_2Me
33b; R_1=R_2=Et; R_3=H

A clue to understanding the overall mechanistic details of the process was gleaned from a study of the Rh(II)-

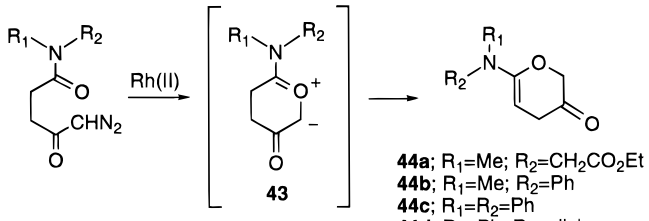
(42) Calculations were performed with the Mopac program (QCPE 506) using the PM3 Hamiltonian.

(43) The formation of **25** as a 2:1 mixture of diastereomers might involve racemization *via* structure **24** or possibly in the preparation of α-diazo ketone **22**.

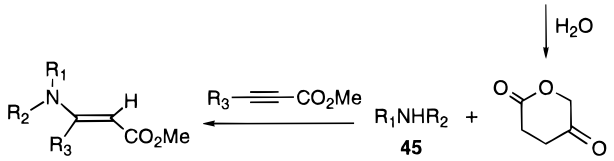
catalyzed reaction of 1-diazo-5-(*N*-methyl-*N*-(*p*-nitrophenyl)amino)-2,5-pentanedione (**36**). When **36** was treated with a catalytic quantity of rhodium(II) acetate in the presence of DMAD, no trace of the spiro epoxy cycloadduct was present in the crude reaction mixture. Instead, the only compound isolated (87%) corresponded to 6-(*N*-methyl-*N*-(*p*-nitrophenyl)amino)-2*H*-pyran-3(4*H*)-one (**37**). This same structure was obtained when the reaction was carried out in the absence of the trapping agent. In sharp contrast to this result, the closely related *p*-methoxy derivative **38** afforded the spiroepoxy cycloadduct **39** (46%) and dimethyl (*N*-(*p*-methoxyphenyl)-*N*-methylamino)maleate (**40**) (15%) and dihydro-2*H*-pyran-2,5(3*H*)-dione (**41**) (15%) (*vide infra*). The cycloaddition reaction of **38** and *N*-phenylmaleimide proceeded in a similar manner, giving rise to the rearranged cycloadduct **42** in 79% isolated yield. Once again, the corresponding *p*-nitro derivative **36** afforded only pyranone **37** when *N*-phenylmaleimide was used as the trapping agent.



A variety of reaction conditions were examined in order to maximize the yield of the rearranged cycloadducts. We found that the highest yields were obtained when the solvent (benzene, $CHCl_3$, or CH_2Cl_2) was rigorously dried. Use of ordinary solvents routinely led to variable amounts of the cycloadduct as well as lactone **41** together with several other hydrolyzed products (*vide infra*). When the reaction was carried out in the absence of a trapping agent, cyclic ketene *N*,*O*-acetals of type **44** were isolated in high yield. These compounds were readily hydrolyzed on standing to give lactone **41** and the corresponding amine **45**. In fact, treatment of the initially formed ketene *N*,*O*-acetals **44** with "wet" benzene in the presence of DMAD (or methyl propiolate) afforded high yields of lactone **41** as well as enamide **46** derived from conjugate addition of the amine onto the activated acetylenic π-bond.[44]



44a; R_1=Me; R_2=CH_2CO_2Et
44b; R_1=Me; R_2=Ph
44c; R_1=R_2=Ph
44d; R_1=Ph; R_2=allyl
44e; R_1=R_2=Et



46a; R_1=Me; R_2=CH_2CO_2Et; R_3=CO_2Me
46b; R_1=Me; R_2=Ph; R_3=CO_2Me
46c; R_1=Me; R_2=Ph; R_3=H
46d; R_1=R_2=Et; R_3=CO_2Me
46e; R_1=R_2=Et; R_3=H

Formation of the epoxy spiro cycloadducts can be attributed to the initial generation of the expected carbonyl ylide dipole **43** by intramolecular cyclization of the keto carbenoid derived from the diazo ketoamide onto the oxygen atom of the amido group. This highly stabilized dipole does not readily undergo 1,3-dipolar cycloaddition but rather transfers a proton to produce the cyclic ketene *N*,*O*-acetal **44**. The formation of **44** comes as no real surprise since one of the characteristic reactions of carbonyl ylides derived from the reaction of α-diazoalkanes with ketones consists of an intramolecular proton transfer. The earliest example of this process was reported by Kharasch and co-workers in 1953,[45] and many related cases have been recorded since that time.[46–49] The overall reaction represents a new synthetic approach to cyclic *N*,*O*-ketene acetals.

The unusual cycloadditions outlined here are envisaged to involve nucleophilic addition of the cyclic ketene *N*,*O*-acetal with the activated π-bond of the dipolarophile to produce zwitterion **47**. The anionic portion of **47** adds to the adjacent carbonyl group, affording a new zwitterionic intermediate (**48**). Under anhydrous conditions, epoxide formation occurs with charge dissipation to produce the observed rearranged cycloadduct (*i.e.*, **31**). Indeed treatment of a pure sample of **44b** (R_1 = Me; R_2 = Ph) with an equivalent of methyl propiolate gave cycloadduct **31** in 89% isolated yield. Similar results were obtained using pyranone **44c** (R_1 = R_2 = Ph) and *N*-phenyl maleimide which afforded cycloadduct **34** in 85% yield. It is also of interest to note that the more electron deficient nature of pyranone **37** (see also **44**; R_1 = Me; R_2 = *p*-$NO_2C_6H_4$) changes its reactivity pattern compared to the *p*-methoxy isomer derived from **38**. Thus, all attempts to induce a reaction between **37** and DMAD or *N*-phenylmaleimide failed to give rise to a spiroepoxy cycloadduct. This is presumably related to the diminished involvement of the nitrogen lone pair of electrons which no longer facilitates nucleophilic addition to the electron-deficient dipolarophile.

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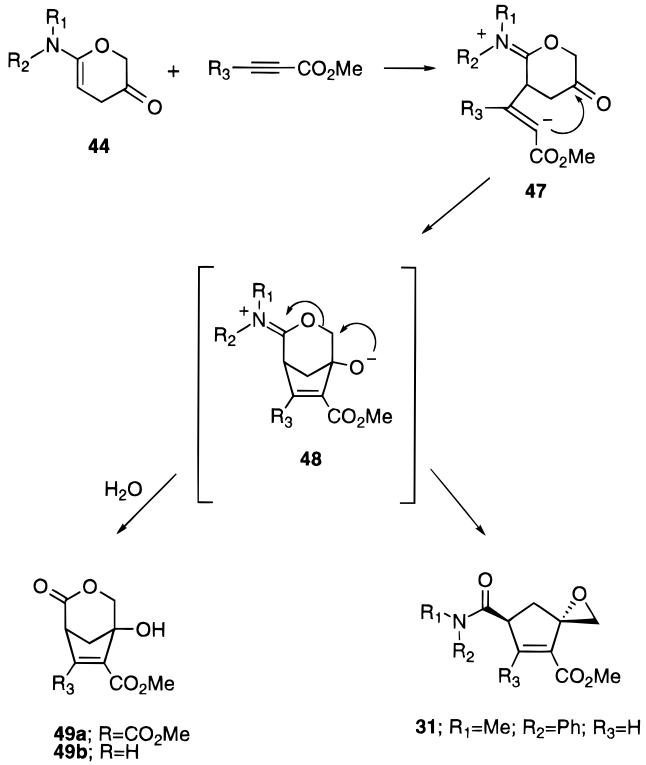
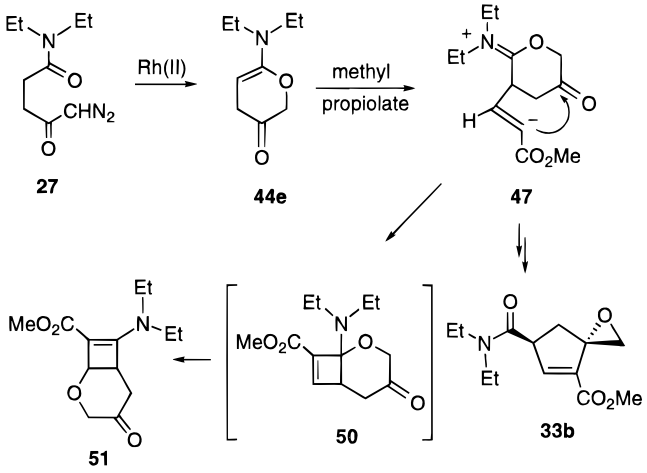
(45) Kharasch, M. S.; Rudy, T.; Nudenberg, W.; Buchi, G. *J. Org. Chem.* **1953**, *18*, 1030.
(46) Lottes, A.; Landgrebe, J. A.; Larsen, K. *Tetrahedron Lett.* **1989**, *30*, 4089.
(47) Gutsche, C. D.; Hillman, M. *J. Am. Chem. Soc.* **1954**, *76*, 2236.
(48) Landgrebe, J. A.; Iranmanesh, H. *J. Org. Chem.* **1978**, *43*, 1244.
(49) Bien, S.; Gillon, A. *Tetrahedron Lett.* **1974**, 3073.

During our investigations of these reactions, we found that the distribution of products obtained from any given system was critically dependent upon the amount of adventitious water present in the solvent. In certain cases, an additional lactone (*i.e.*, **49**) could also be isolated as a minor product from the cycloaddition reaction. For example, in the Rh(II)-catalyzed reaction of diazo ketoamides **26** and **27** with DMAD, lactone **49a** (R_3 = CO_2Me) was obtained in *ca*. 15% yield. The structure assignment of **49a** is based upon the following characteristic spectral data: The correct molecular weight (256) was obtained from the HRCI mass spectrum; the IR (3460, 1740, and 1730 cm^{-1}) and ^{13}C-NMR spectra indicate the presence of three carbonyl groups and two vinylic carbons; the ^1H-NMR spectrum shows absorptions for two methoxy groups and the coupling patterns expected for the remaining five protons (see Experimental Section). An analogous product (**49b**) was obtained in 30% yield when methyl propiolate was used as the trapping agent. The formation of these lactones can be attributed to the hydrolysis of the zwitterionic intermediate **48**, and their isolation provides convincing support for the mechanism outlined in Scheme 3.

Scheme 3



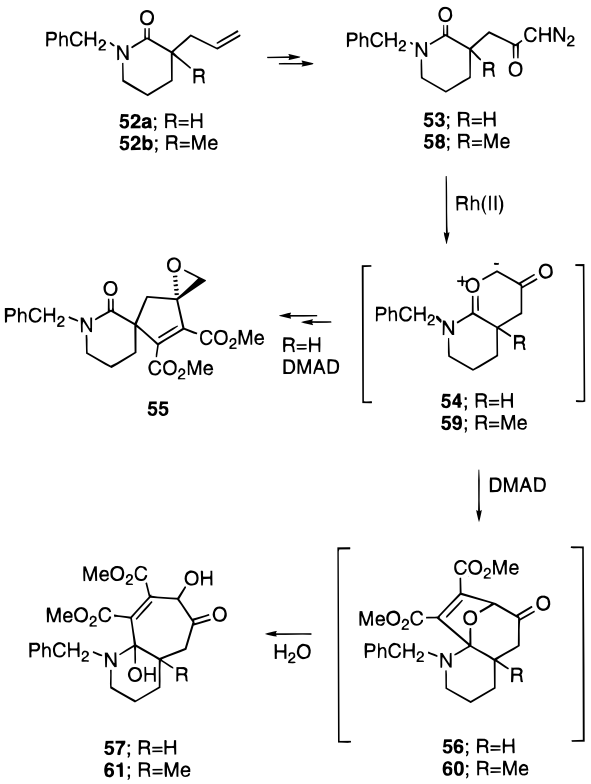
An interesting variation of the cycloaddition reaction comes from a study of the Rh(II)-catalyzed reaction of diazo ketoamide **27** with methyl propiolate. Exposure of **27** to $Rh_2(OAc)_4$ in anhydrous benzene with methyl propiolate over molecular sieves afforded a mixture of two products. The major product corresponded to the spiro-epoxy cycloadduct **33b** (65%) whereas the minor component was assigned as 8-carbomethoxy-7-(diethylamino)-2-oxabicyclo[4.2.0]oct-7-en-4-one (**51**) (28%). Characteristic structural data for **51** (IR, ^1H- and ^{13}C-NMR) show the presence of a keto and ester group. The six methylene protons on the pyranone backbone result from geminal and vicinal couplings (see Experimental Section). The mechanism for this alternate cycloaddition has not been unequivocally established, but one reasonable possibility is outlined below. Here it is proposed that the cyclic ketene *N*,*O*-acetal undergoes stepwise 2 + 2 cycloaddition[50] (*via* zwitterion **47**) with methyl propiolate to give **50** which undergoes a subsequent 1,3-sigmatropic shift to give the thermodynamically more stable isomer **51**.



A final area of study involves the Rh(II)-catalyzed reaction of cyclic diazo ketoamides **53** and **58** derived from the *N*-benzylpiperidinone ring system. Allylation of *N*-benzyl-2-piperidone followed by ozonolysis allowed access to the expected carboxylic acid which was easily transformed by standard methodology to the desired diazo ketoamide **53**. The Rh(II)-catalyzed reaction of **53** in the presence of DMAD afforded a mixture of two compounds whose structures were assigned as the spiro epoxy adduct **55** (25%) and the ring-opened carbonyl ylide derived cycloadduct **57** (53%). The formation of **57** is envisaged to arise *via* dipolar cycloaddition of the initially formed dipole **54** across DMAD to give **56** which is subsequently converted to **57** on chromatographic work-up. The lone pair of electrons on the amide nitrogen undoubtedly assists in opening the oxy bridge generating a transient iminium ion which reacts further with water to give **57**. In this case, the rate of the 1,4-proton transfer has been sufficiently diminished to allow the bimolecular dipolar cycloaddition to compete. This may be related to the rigid nature of the cyclic system and the greater difficulty in achieving the correct geometry for the internal hydrogen shift. Cycloaddition would be expected to take place exclusively from the carbonyl ylide dipole if the α-position of the piperidone ring was blocked with an alkyl group. Indeed, we found that the Rh(II)-catalyzed reaction of diazo ketoamide **58** with DMAD afforded only the carbonyl ylide derived product **61** in good yield.

In conclusion, we note the following points: (1) α-diazo ketones containing an amido group in the γ-position undergo a novel Rh(II)-catalyzed cycloaddition with olefinic and acetylenic dipolarophiles. (2) A mechanism involving the initial formation of a carbonyl ylide dipole followed by proton loss to form a cyclic ketene *N*,*O*-acetal has been proposed. In the absence of any significant amount of water, the ketene *N*,*O*-acetal undergoes conjugate addition with the activated π-bond of the dipo-

(50) For some related 2 + 2 cycloadditions of enamines with acetylenic esters, see: Menachery, M. D.; Carroll, P.; Cava, M. P. *Tetrahedron Lett.* **1983**, *24*, 167. Lamm, B.; Aurell, C. J. *Acta Chem. Scand.* **1982**, *B36*, 435. Lamm, B.; Andersen, L.; Aurell, C. J. *Tetrahedron Lett.* **1983**, *24*, 2413.



larophile to eventually give an amido cyclopentyl epoxide. (3) The high efficiency of the process in conjunction with the intriguing chemistry of the resulting cycloadducts presents numerous synthetic possibilities which will be reported on at a later date.

Experimental Section

Melting points are uncorrected. Mass spectra were determined at an ionizing voltage of 70 eV. Unless otherwise noted, all reactions were performed in oven-dried glassware under an atmosphere of dry nitrogen. Solutions were evaporated under reduced pressure with a rotary evaporator, and the residue was chromatographed on a silica gel column using an ethyl acetate-hexane mixture as the eluent unless specified otherwise.

Preparation and Rhodium(II)-Catalyzed Reaction of *o*-(*N*-(Carbethoxymethyl)-*N*-methylcarbamyl)-α-diazoacetophenone (14). A mixture containing 3.07 g (20 mmol) of sarcosine ethyl ester hydrochloride, 3.0 g (20 mmol) of phthalic anhydride, and 2 mL of pyridine in 50 mL of THF was stirred at rt for 10 h. The mixture was diluted with 20 mL of water, acidified to pH 5, and extracted with ethyl acetate. The combined organic layer was washed with water, dried over $MgSO_4$, and concentrated under reduced pressure. The resulting oil was identified as *o*-(*N*-(carbethoxymethyl)-*N*-methylcarbamyl)benzoic acid whose NMR spectrum indicates it to be a 2:1 mixture of nitrogen invertomers: ^{1}H NMR (90 MHz, $CDCl_3$) major δ 1.10−1.35 (m, 3H), 2.85 (s, 3H), 4.00−4.35 (m, 2H), 4.35 (s, 2H), 7.30−8.25 (m, 4H), and 10.90 (s, 1H); minor δ 1.10−1.35 (m, 3H), 3.18 (s, 3H), 3.84 (s, 2H), 4.00−4.35 (m, 2H), 7.30−8.25 (m, 4H), and 10.90 (s, 1H).

The above acid was suspended in 200 mL of ether, and 1.7 mL of methyl chloroformate was added. The solution was allowed to stir for 30 min at 25 °C, and then 1.4 mL of triethylamine was added. After stirring for an additional 30 min, the reaction mixture was filtered and the filtrate was allowed to react with 40 mmol of diazomethane in ether at 0 °C for 12 h. Removal of the solvent under reduced pressure followed by silica gel chromatography of the residue gave 3.2 g (55%) of *o*-(*N*-carbethoxymethyl)-*N*-methylcarbamyl)-α-diazoacetophenone (**14**): IR (neat) 2110, 1750, 1650, 1365, and 1210 cm^{-1}. The NMR spectrum indicates that **14** exists as a 2:1 mixture of nitrogen invertomers. NMR (300 MHz, $CDCl_3$) major: δ 1.32 (t, 3H, J = 7.1 Hz), 2.90 (s, 3H), 4.24 (q, 2H, J = 7.1 Hz), 4.34 (s, 2H), 5.97 (s, 1H), and 7.31−7.66 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.5, 37.3, 47.9, 55.6, 60.6, 126.7, 127.0, 128.5, 131.3, 135.1, 168.4, 170.8 and 185.9. Minor: δ 1.23 (t, 3H, J = 7.2 Hz), 3.17 (s, 3H), 4.16 (q, 2H, J = 7.1 Hz), 3.89 (s, 2H), 5.93 (s, 1H), and 7.31−7.66 (m, 4H); ^{13}C-NMR (75 MHz, $CDCl_3$) δ 13.4, 33.2, 52.3, 55.4, 60.7, 126.4, 126.9, 131.3, 134.1, 135.2, 168.4, 170.7 and 186.1.

A mixture containing 300 mg (1.04 mmol) of **14** and 1.2 equiv of DMAD in 3 mL of benzene was allowed to react with 2 mg of rhodium(II) acetate. The reaction mixture was stirred at rt for 30 min until no more N_2 had evolved. Removal of the solvent under reduced pressure followed by silica gel chromatography afforded 5-(*N*-(carbethoxymethyl)-*N*-methylamino)-6,7-dicarbomethoxy-8,9-dihydro-9-oxa-5,8-epoxy-5*H*-benzocycloheptene (**20**) (90%) as a clear oil: IR (neat) 1740, 1730, 1460, 1320, and 770 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.29 (t, 3H, J = 7.1 Hz), 2.64 (s, 3H), 3.58 (s, 2H), 3.77 (s, 3H), 3.80 (s, 3H), 4.23 (q, 2H, J = 7.1 Hz), 5.39 (s, 1H), 7.44−7.58 (m, 3H), and 7.90 (d, 1H, J = 7.0 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.6, 37.1, 52.1, 52.2, 53.4, 60.2, 84.8, 106.5, 124.3, 126.4, 127.8, 129.3, 132.6, 135.4, 140.8, 150.3, 160.4, 162.5, 169.8, and 187.6. Anal. Calcd for $C_{20}H_{21}NO_8$: C, 59.53; H, 5.25; N, 3.47, found C, 59.39; H, 5.12; N, 3.26.

Preparation and Rhodium(II)-Catalyzed Reaction of 5-(*N*-(Carbethoxymethyl)-*N*-methylamino)-1-diazopentane-2,5-dione (17). A 2.0 g sample of **17** was prepared in 45% yield from 3.0 g (19.5 mmol) of sarcosine ethyl ester hydrochloride and 2.0 g (20 mmol) of succinic anhydride using the same procedure as described above: IR (neat) 2105, 1750, 1650, 1380, and 1210 cm^{-1}. The high-field NMR spectrum showed that **17** exists as a 4:1 mixture of nitrogen invertomers. ^{1}H NMR (300 MHz, $CDCl_3$) major: δ 1.27 (t, 3H, J = 7.1 Hz), 2.62−2.80 (m, 4H), 3.11 (s, 3H), 4.10 (s, 2H), 4.17 (q, 2H, J = 7.1 Hz), and 5.42 (brs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.4, 27.1, 34.4, 35.7, 48.9, 54.0, 60.4, 168.6, 171.4 and 193.2. Minor: δ 1.30 (t, 3H, J = 7.1 Hz), 2.55−2.70 (m, 4H), 2.97 (s, 3H), 4.10 (s, 2H), 4.23 (q, 2H, J = 7.1 Hz), and 5.42 (bs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.4, 26.8, 34.3, 34.4, 50.8, 54.0, 61.0, 168.3, 171.2, and 193.2.

Treatment of 480 mg (2 mmol) of **17** and 250 mg (2 mmol) of DMAD in 2 mL of $CHCl_3$ with 2 mg of rhodium(II) acetate afforded a mixture of three products which were separated by silica gel chromatography. The minor component of the mixture was identified as dimethyl 2-(*N*-(carbethoxymethyl)-*N*-methylamino)maleate (**46a**) (15%): IR (neat) 1750, 1705, 1595, 1215, 1165, and 1115 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.29 (t, 3H, J = 7.1 Hz), 2.95 (s, 3H), 3.65 (s, 3H), 3.85 (s, 2H), 3.91 (s, 3H), 4.22 (q, 2H, J = 7.1 Hz), and 4.69 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.5, 38.6, 50.3, 52.4, 53.4, 60.9, 86.3, 153.7, 165.0, 167.1, and 167.7. Anal. Calcd for $C_{11}H_{17}NO_6$: C, 54.94; H, 6.61; N, 5.40, found C, 54.83, H, 6.47, N, 5.29.

The second minor component (18%) was assigned as 6,7-dicarbomethoxy-5-hydroxy-3-oxabicyclo[3.2.1]oct-6-en-2-one (**49a**) (*vide infra*). The major product was a clear oil whose structure was assigned as 6-(*N*-(carbethoxymethyl)-*N*-methyl)-carbamyl)-4,5-dicarbomethoxy-1-oxaspiro[2.4]hept-4-ene (**21**) (60%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.27 (t, 3H, J = 7.2 Hz), 2.28 (dd, 1H, J = 14.0 and 9.0 Hz), 2.45 (dd, 1H, J = 14.0 and 6.0 Hz), 3.06 (d, 1H, J = 4.1 Hz), 3.19 (s, 3H), 3.37 (d, 1H, J = 4.1 Hz), 3.76 (s,3H), 3.78 (s, 3H), 4.10 (d, 1H, J = 17.1 Hz), 4.18 (q, 2H, J = 7.2 Hz), 4.23 (d, 1H, J = 17.1 Hz), and 4.54 (dd, 1H, J = 9.0 and 6.0 Hz). Anal. Calcd for $C_{16}H_{21}NO_8$: C, 54.07; H, 5.96; N, 3.94, found C, 53.85, H, 5.87; N, 3.71.

Preparation and Rhodium(II)-Catalyzed Reaction of 5-(2′-Carbometh-oxypyrrolidinyl)-1-diazopentane-2,5-dione (22). To 50 mL of a THF solution containing 3.33 g (20.1 mmol) of L-proline methyl ester hydrochloride was added a suspension containing 0.80 g of NaH in 20 mL of THF. The resulting mixture was stirred for 20 min at 25 °C and then 2.0 g (20 mmol) of succinic anhydride was added. The reaction mixture was allowed to stir at rt overnight and was then washed with dilute HCl and dried over $MgSO_4$. Removal of the solvent under reduced pressure left a colorless oil which

corresponded to 3-((2′-carbomethoxypyrrolidinyl)carbonyl)-propanoic acid: ^{1}H NMR (90 MHz, $CDCl_3$) δ 1.80−2.50 (m, 4H), 2.70 (s, 4H), 3.55−3.70 (m, 2H), 3.73 (s, 3H), 4.55 (t, 1H, J = 5.4 Hz), and 9.68 (s, 1H).

Treatment of the above acid with methyl chloroformate/triethylamine followed by diazomethane according to the standard procedure gave 2.0 g (40%) of 5-(2′-carbomethoxypyrrolidinyl)-1-diazopentane-2,5-dione (**22**) as a yellow oil: IR (neat) 2110, 1750, 1645, 1440, and 1380 cm^{-1}. The high-field NMR spectrum indicated that **22** exists as a 4:1-mixture of nitrogen invertomers. ^{1}H NMR (300 MHz, $CDCl_3$) major: δ 1.94−2.25 (m, 4H), 2.52−2.85 (m, 4H), 3.50−3.71 (m, 2H), 3.71 (s, 3H), 4.46 (dd, 1H, J = 8.4 and 3.6 Hz), and 5.42 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 24.0, 28.2, 28.5, 34.2, 46.2, 51.5, 54.0, 58.0, 169.6, 172.1 and 193.2. Minor: δ 1.86−2.25 (m, 4H), 2.52−2.85 (m, 4H), 3.50−3.71 (m, 2H), 3.77 (s, 3H), 4.54 (dd, 1H, J = 9.5 and 2.6 Hz), and 5.42 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 21.9, 28.2, 30.7, 34.2, 45.7, 51.9, 54.0, 58.6, 169.8, 171.9, and 193.2.

Treatment of 260 mg (1.03 mmol) of **22** and 150 mg of DMAD in 1 mL of $CHCl_3$ with 2 mg of rhodium(II) acetate afforded a mixture of several products. The first fraction isolated (5%) was assigned as dimethyl (2′-carbomethoxypyrrolidinyl)maleate: IR (oil) 1750, 1700, 1585, 1235, 1200, and 1160 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.97−2.17 (m, 3H), 2.17−2.33 (m, 1H), 3.26−3.40 (m, 1H), 3.40−3.55 (m, 1H), 3.63 (s, 3H), 3.74 (s, 3H), 3.89 (s, 3H), 4.17 (d, 1H, J = 8.1 Hz), and 4.59 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 22.5, 29.8, 47.9, 50.2, 51.9, 52.2, 60.3, 85.8, 150.7, 165.0, 167.2, and 171.6. Anal. Calcd for $C_{12}H_{17}NO_6$: C, 53.12; H, 6.32; N, 5.17, found C, 53.04; H, 6.36; N, 5.01.

The second fraction (10%) was a pale yellow oil whose structure was assigned as 6,7-dicarbomethoxy-5-hydroxy-3-oxabicyclo[3.2.1]oct-6-en-2-one (**49a**) on the basis of its spectral data: IR (neat) 3460, 1740, 1730, 1275, 1145, and 1030 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.55 (d, 1H, J = 10.9 Hz), 2.65 (ddd, 1H, J = 10.9, 4.5, and 1.4 Hz), 3.69 (d, 1H, J = 4.5 Hz), 3.82 (s, 3H), 3.88 (s, 3H), 4.33 (brs, 1H), 4.37 (d, 1H, J = 10.8 Hz), and 4.45 (dd, 1H, J = 10.8 and 1.4 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 42.9, 45.8, 52.2, 52.3, 73.0, 77.2, 137.1, 144.9, 161.6, 163.3, and 165.1; HRMS calcd for $C_{11}H_{12}O_7$ 256.0583, found 256.0582. Anal. Calcd for $C_{11}H_{12}O_7$: C, 51.55; H, 4.72, found C, 51.32; H, 4.57.

The third fraction (60%) was assigned as 6-*trans*-((2′-carbomethoxypyrrolidinyl)carbonyl)-4,5-dicarbomethoxy-1-oxaspiro[2.4]hept-4-ene (**25**) as a 2:1 mixture of two stereoisomers. ^{1}H NMR (300 MHz, $CDCl_3$) major: δ 1.92−2.30 (m, 5H), 2.44 (dd, 1H, J = 14.2 and 4.4 Hz), 3.07 (d, 1H, J = 4.4 Hz), 3.34 (d, 1H, J = 4.4 Hz), 3.55−3.80 (m, 2H), 4.34 (t, 1H, J = 6.3 Hz), and 4.51 (dd, 1H, J = 8.8 and 4.4 Hz). Anal. Calcd for $C_{17}H_{21}NO_8$: C, 55.57; H, 5.76; N, 3.81, found C, 55.39; H, 5.66; N, 3.64. All attempts to separate the two diastereomers failed.

Preparation and Rhodium(II)-Catalyzed Reaction of 1-Diazo-5-(methylphenylamino)pentane-2,5-dione (26). A solution containing 2.0 g (20 mmol) of succinic anhydride and 2.15 g (20 mmol) of *N*-methylaniline in 50 mL of THF was stirred at rt for 4 h. Removal of the solvent under reduced pressure left 3.5 g (85%) of *N*-methyl-*N*-phenylsuccinimic acid, mp 83−84 °C: ^{1}H NMR (90 MHz, $CDCl_3$) δ 2.36 (t, 2H, J = 6.0 Hz), 2.63 (t, 2H, J = 6.0 Hz), 3.31 (s, 3H), 7.20−7.55 (m, 5H), and 10.91 (s, 1H). The above acid was treated with methyl chloroformate/triethylamine and diazomethane in the standard manner to give 1-diazo-5-(methylphenylamino)pentane-2,5-dione (**26**) in 73% yield as a yellow oil: IR (neat) 2110, 1670, 1655, 1380, and 710 cm^{-1}; NMR (300 MHz, $CDCl_3$) δ 2.40 (t, 2H, J = 6.4 Hz), 2.61 (brs, 2H), 3.25 (s, 3H), 5.34 (brs, 1H), and 7.20-7.48 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 28.4, 34.9, 36.7, 53.9, 126.7, 127.2, 129.2, 143.1, 170.8, and 193.2.

To a mixture containing 465 mg (2.01 mmol) of **26** and 1.2 equiv of DMAD in 3 mL of benzene was added 2 mg of rhodium(II) acetate. After stirring for 10 min at rt, the solvent was removed under reduced pressure and the residue was subjected to silica gel chromatography. The major fraction (60%) isolated was a clear oil whose structure was assigned as 4,5-dicarbomethoxy-6-*trans*-(*N*-methyl-*N*-phenylcarbamyl)-1-oxaspiro[2.4]hept-4-ene (**30**): IR (neat) 1730, 1660, 1300, 1275, and 710 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.02 (dd, 1H, J = 14.4 and 9.1 Hz), 2.40 (dd, 1H, J = 14.4 and 5.9 Hz), 3.00 (d, 1H, J = 4.6 Hz), 3.29 (s, 3H), 3.33 (d, 1H, J = 4.6 Hz), 3.75 (s, 3H), 3.78 (s, 3H), 4.11 (dd, 1H, J = 9.1 and 5.9 Hz), and 7.22−7.50 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 33.6, 36.9, 45.8, 51.7, 52.5, 66.7, 126.8, 127.7, 129.4, 139.9, 142.5, 142.8, 162.4, 163.0, and 171.4. Anal. Calcd for $C_{18}H_{19}NO_6$: C, 62.59; H, 5.55; N, 4.06, found C, 62.51; H, 5.43; N, 3.96. The minor fraction (15%) was identified as 6,7-dicarboxmethoxy-5-hydroxy-3-oxabicyclo[3.2.1]oct-6-en-2-one (**49a**).

The reaction was also carried out in the absence of a dipolarophile. To a sample containing 240 mg (1.04 mmol) of **26** in 3 mL of chloroform was added 2 mg of rhodium(II) acetate. After stirring for 15 min, the crude NMR spectrum showed the presence of 7-(methylphenylamino)-2*H*-pyran-3(4*H*)-one (**44b**) (70%) which was isolated as an extremely labile oil: IR (neat) 1750, 1610, 1510, 1135, and 715 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.01 (d, 2H, J = 3.9 Hz), 3.15 (s, 3H), 4.30 (s, 2H), 4.46 (t, 1H, J = 3.9 Hz), 6.94−7.05 (m, 2H), and 7.24−7.32 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 34.7, 38.6, 72.4, 80.2, 119.3, 121.4, 128.3, 146.1, 154.6 and 207.3. Anal. Calcd for $C_{12}H_{13}NO_2$: C, 70.90; H, 6.45; N, 6.89, found C, 70.74; H, 6.43; N, 6.82.

An entirely different set of products was obtained if the reaction of **26** was carried out with DMAD in the presence of some water. To a mixture containing 346 mg (1.5 mmol) of **26**, 1.2 equiv of DMAD, and 2.0 equiv of water in 3 mL of benzene was added 2 mg of rhodium(II) acetate. After stirring for 30 min at 25 °C, the mixture was concentrated to dryness and the crude residue was subjected to silica gel chromatography. The major fraction (45%) corresponded to dimethyl 2-(methylphenylamino)maleate (**46b**), mp 71−72 °C: IR (neat) 1750, 1700, 1580, and 1160 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.22 (s, 3H), 3.65 (s, 3H), 3.68 (s, 3H), 4.80 (s, 1H), and 7.18−7.40 (m, 5H); ^{13}C-NMR (75 MHz, $CDCl_3$) 40.2, 50.3, 52.0, 87.5, 125.9, 126.8, 128.8, 143.9, 153.5, 164.7 and 167.2; Anal. Calcd for $C_{13}H_{15}NO_4$: C, 62.64; H, 6.07; N, 5.62, found C, 62.62, H, 6.09, N, 5.59.

The second fraction (40%) isolated from the column was a clear oil whose structure was assigned as dihydro-2*H*-pyran-2,5(3*H*)-dione (**41**): IR (neat) 1760, 1735, 1430, 1310, and 1150 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.76 (t, 2H, J = 7.2 Hz), 2.93 (t, 2H, J = 7.2 Hz), and 4.69 (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 27.0, 33.1, 72.4, 169.1, and 203.2. Anal. Calcd for $C_5H_6O_3$: C, 62.59; H, 5.55, found C, 62.51; H, 5.43. The last fraction (10%) isolated corresponded to 6,7-dicarbomethoxy-5-hydroxy-3-oxabicyclo[3.2.1]oct-6-en-2-one (**49a**).

The rhodium(II)-catalyzed reaction of a 460 mg (1.99 mmol) sample of **26** was also carried out in the presence of 1.2 equiv of methyl propiolate in 2 mL of CH_2Cl_2 at 25 °C for 1 h. Two major products were isolated by silica gel chromatography. The first fraction (25%) corresponded to 4-carbomethoxy-6-*trans*-(*N*-methyl-*N*-phenylcarbamyl)-1-oxaspiro[2.4]hept-4-ene (**31**): IR (oil) 1735, 1665, 1510, 1395, and 715 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.94 (dd, 1H, J = 14.4 and 8.4 Hz), 2.67 (dd, 1H, J = 14.4 and 5.4 Hz), 2.96 (d, 1H, J = 5.1 Hz), 3.30 (s, 3H), 3.69 (s, 3H), 3.78 (d, 1H, J = 5.1 Hz), 3.87 (ddd, 1H, J = 8.4, 5.4, and 2.3 Hz), 6.90 (d, 1H, J = 2.3 Hz), 7.23 (d, 2H, J = 7.5 Hz), and 7.40−7.55 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 34.9, 37.3, 44.8, 51.0, 51.5, 65.6, 126.7, 127.9, 129.6, 134.0, 142.6, 148.4, 162.1, and 171.2. Anal. Calcd for $C_{16}H_{17}NO_4$: C, 66.87; H, 5.97; N, 4.88, found C, 66.71; H, 5.83; N, 4.92. Cycloadduct **31** was obtained in 89% isolated yield by heating a sample of pyranone **44b** with methyl propiolate in anhydrous benzene at 40 °C for 3 h.

The second fraction (30%) isolated from the column was assigned as 6-carbomethoxy-5-hydroxy-3-oxabicyclo[3.2.1]oct-6-en-2-one (**49b**): IR (oil) 3500, 1760, 1735, 1290, 1170, and 1070 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.50 (d, 2H, J = 5.5 Hz), 3.41 (dd, 1H, J = 5.5 and 3.6 Hz), 2.82 (s, 3H), 4.20 (d, 1H, J = 10.5 Hz), 4.33 (d, 1H, J = 10.5 Hz), 4.39 (bs, 1H), and 7.00 (d, 1H, J = 3.6 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 42.6, 45.1, 51.7, 73.5, 75.4, 139.1, 141.9, 163.7, and 165.6. Anal. Calcd for $C_9H_{10}O_5$: C, 54.53; H, 5.09, found C, 54.36; H, 5.12.

A third fraction (10%) was also isolated from the silica gel

column and was identified as methyl 3-(methylphenylamino)-2-propenoate[51] (**46c**): IR (oil) 1710, 1630, 1600, 1510, and 1140 cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$) δ 3.23 (s, 3H), 3.70 (s, 3H), 4.92 (d, 1H, J = 13.2 Hz), 7.12 (d, 3H, J = 7.5 Hz), 7.34 (d, 2H, J = 7.5 Hz), and 7.93 (d, 1H, J = 13.2 Hz).

The rhodium(II) acetate catalyzed reaction of 460 mg (1.99 mmol) of **26** with 350 mg of *N*-phenylmaleimide was carried out in 2 mL of $CHCl_3$ and afforded 6-*trans*-(*N*-methyl-*N*-phenylcarbamyl)-4,5-*trans*-((*N*-phenylimino)dicarbonyl)-1-oxaspiro[2.4]-heptane (**32**) in 70% yield; mp 194−195 °C; IR (KBr) 1715, 1650, 1600, 1500, and 720 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.70 (dd, 1H, J = 14.4 and 7.1 Hz), 2.76 (dd, 1H, J = 14.4 and 11.4 Hz), 2.90 (d, 1H, J = 8.8 Hz), 2.95 (d, 1H, J = 4.1 Hz), 3.21 (dd, 1H, J = 9.7 and 8.8 Hz), 3.30 (s, 3H), 3.43 (d, 1H, J = 4.1 Hz), 3.45 (ddd, 1H, J = 11.4, 9.7, and 7.1 Hz), and 7.28−7.55 (m, 10H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 34.9, 37.3, 43.6, 45.9, 47.1, 50.7, 64.6, 125.9, 126.9, 127.9, 128.1, 128.6, 129.4, 131.1, 142.8, 169.3, 173.6, and 175.1. Anal. Calcd for $C_{22}H_{20}N_2O_4$: C, 70.20; H, 5.36; N, 7.44, found C, 70.28; H, 5.38; N, 7.41.

Preparation and Rhodium(II)-Catalyzed Reaction of 1-Diazo-5-(diethylamino)pentane-2,5-dione (27). A sample of **27** was prepared in 44% yield starting from 3.5 g (20.2 mmol) of *N*,*N*-diethylsuccinamic acid using the standard procedure described above: IR (oil) 2110, 1790, 1640, 1380, 1145, and 1100 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.09 (t, 3H, J = 7.4 Hz), 1.20 (t, 3H, J = 7.4 Hz), 2.68 (brs, 4H), 3.34 (q, 2H, J = 7.4 Hz), 3.36 (q, 2H, J = 7.4 Hz), and 5.41 (brs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 12.3, 13.4, 27.0, 34.7, 39.5, 41.1, 53.9, 169.6, and 193.6.

The reaction between 400 mg (2.03 mmol) of **27** and 1.2 molar equiv of DMAD in 3 mL of $CHCl_3$ was carried out in the presence of 2 mg of rhodium(II) acetate. Standard workup afforded three products. The major fraction (70%) was a clear oil whose structure corresponded to 4,5-dicarbomethoxy-6-*trans*-(*N*,*N*-diethylcarbamyl)-1-oxaspiro[2.4]hept-4-ene (**33a**): IR (neat) 1730, 1640, 1440, 1300, 1270, and 1230 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.11 (t, 3H, J = 7.1 Hz), 1.25 (t, 3H, J = 7.1 Hz), 2.36 (dd, 1H, J = 14.2 and 5.4 Hz), 2.41 (dd, 1H, J = 14.2 and 8.4 Hz), 3.05 (d, 1H, J = 4.6 Hz), 3.35 (dq, 1H, J = 14.2 and 7.1 Hz), 3.38 (q, 2H, J = 7.1 Hz), 3.39 (d, 1H, J = 4.6 Hz), 3.49 (dq, 1H, J = 14.2 and 7.1 Hz), 3.76 (s, 3H), 3.78 (s, 3H), and 4.40 (dd, 1H, J = 8.4 and 5.4 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 12.3, 14.0, 33.6, 40.0, 41.8, 44.9, 51.6, 51.7, 52.7, 67.0, 140.2, 142.1, 162.7, 162.9, and 170.4. Anal. Calcd for $C_{15}H_{21}NO_6$: C, 57.85; H, 6.80; N, 4.50, found C, 57.79; H, 6.87; N, 4.47.

The second product (15%) isolated from the column was identified as lactone **49a**, and the third fraction (10%) was identified as dimethyl (diethylamino)maleate[52] (**46d**): IR (oil) 1750, 1700, 1580, 1165, and 1135 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.18 (t, 6H, J = 7.1 Hz), 3.18 (q, 4H, J = 7.1 Hz), 3.63 (s, 3H), 3.93 (s, 3H), and 4.61 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 12.1, 12.2, 44.3, 44.4, 50.0, 52.2, 82.2, 153.1, 165.5, and 167.7.

The reaction between 400 mg (2.03 mmol) of **27** and 180 mg of methyl propiolate in 2 mL of chloroform with 2 mg of rhodium(II) acetate produced a mixture of four products. The first fraction (10%) corresponded to methyl 3-(diethylamino)-2-propenoate[53] (**46e**): IR (oil) 1690, 1610, 1195, 1155, 1115 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.16 (t, 6H, J = 7.1 Hz), 3.19 (q, 4H, J = 7.1 Hz), 3.66 (s, 3H), 4.57 (d, 1H, J = 13.1 Hz), and 7.44 (d, 1H, J = 13.1 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 29.1, 49.8, 82.3, 150.4, and 169.7.

The second fraction (15%) was a clear oil whose structure was assigned as 8-carbomethoxy-7-(diethylamino)-2-oxabicyclo-[4.2.0]oct-7-en-4-one (**51**): IR (oil) 1735, 1690, 1620, 1200, 1140, 1125, and 1080 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.18 (brs, 6H), 2.70 (dd, 1H, J = 14.9 and 6.3 Hz), 2.91 (dd, 1H, J = 14.9 and 4.5 Hz), 3.15 (q, 2H, J = 6.7 Hz), 3.35 (ddd, 1H, J = 6.3, 4.5 and 4.4 Hz), 3.67 (s, 3H), 3.70−3.95 (m, 2H), 4.00 (d, 1H, J = 17.6 Hz), 4.15 (d, 1H, J = 17.6 Hz), and 4.85 (d, 1H, J = 4.4 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 12.9, 13.6, 27.2, 28.6, 40.0, 40.4, 43.5, 49.9, 68.1, 89.5, 157.2, 162.5 and 209.8. Anal. Calcd for $C_{13}H_{19}NO_4$: C, 61.63; H, 7.56; N, 5.53, found C, 61.54; H, 7.39; N, 5.29.

The third fraction (10%) was identified as 6-carbomethoxy-5-hydroxy-3-oxabicyclo[3.2.1]oct-6-en-2-one (**49b**), and the last fraction (35%) was a clear oil whose structure was assigned as 4-carbomethoxy-6-(*N*,*N*-diethylcarbamyl)-1-oxaspiro[2.4]-hept-4-ene (**33b**): ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.13 (t, 3H, J = 7.1 Hz), 1.24 (t, 3H, J = 7.1 Hz), 2.24 (dd, 1H, J = 14.3 and 8.5 Hz), 2.69 (dd, 1H, J = 14.3 and 5.3 Hz), 3.00 (d, 1H, J = 5.0 Hz), 3.40 (q, 4H, J = 7.1 Hz), 3.72 (s, 3H), 3.82 (d, 1H, J = 5.0 Hz), 4.10 (ddd, 1H, J = 8.5, 5.3, and 2.7 Hz), and 7.03 (d, 1H, J = 2.7 Hz). Anal. Calcd for $C_{13}H_{19}NO_4$: C, 61.63; H, 7.56; N, 5.53, found C, 61.42; H, 7.39; N, 5.50.

Preparation and Rhodium(II)-Catalyzed Reaction of 1-Diazo-5-(*N*,*N*-diphenylamino)-2,5-pentanedione (28). Treatment of 2.7 g (10 mmol) of 4-(*N*,*N*-diphenylamino)-4-oxobutanoic acid[54] with 0.8 mL (10 mmol) of methyl chloroformate and 1.4 mL of triethylamine followed by 20 mmol of diazomethane in ether according to the standard procedure gave 2.1 g (74%) of α-diazo ketoamide **28** as a yellow crystalline solid, mp 128−129 °C: IR (neat) 2100, 1668, 1640, 1490, and 705 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.57 (t, 2H, J = 5.8 Hz), 2.66 (t, 2H, J = 5.8 Hz), 5.31 (s, 1H), and 7.31 (brs, 10H). Anal. Calcd for $C_{17}H_{15}N_3O_2$: C, 69.61; H, 5.15; N, 14.33, found C, 69.73; H, 5.18; N, 14.24.

The reaction of 450 mg (1.53 mmol) of α-diazo ketoamide **28** in 5 mL of $CHCl_3$ with 2 mg of rhodium(II) acetate at rt for 30 min afforded 6-(*N*,*N*-diphenyl-amino)-2*H*-pyran-3(4*H*)-one (**44c**) in 71% yield; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.98 (d, 2H, J = 3.4 Hz), 4.33 (s, 2H), 4.58 (t, 1H, J = 3.4 Hz), and 7.05−7.45 (m, 10H). This compound was quite labile to moisture and it was not possible to obtain an analytically pure sample. Instead, treatment of **44c** with 300 mg of *N*-phenyl maleimide afforded 6-*trans*-((*N*,*N*-diphenylamino)carbonyl)-4,5-*trans*-((*N*-phenylimino)dicarbonyl)-1-oxaspiro[2.4]-heptane (**34**) in 85% yield as a clear oil: IR (neat) 1710, 1662, 1491, 1384, and 706 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.78 (dd, 1H, J = 14.6 and 6.9 Hz), 2.79 (dd, 1H, J = 14.6 and 10.8 Hz), 2.94 (d, 1H, J = 8.0 Hz), 2.96 (d, 1H, J = 3.9 Hz), 3.30 (dd, 1H, J = 10.6 and 8.0 Hz), 3.43 (d, 1H, J = 3.9 Hz), 3.65 (ddd, 1H, J = 10.8, 10.6, and 6.9 Hz), and 7.25−7.60 (m, 15H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 34.9, 44.1, 46.1, 47.0, 50.8, 64.6, 126.1, 126.3, 128.1, 128.2, 128.3, 128.5, 128.6, 129.5, 131.1, 141.8, 141.9, 169.5, 173.6, and 175.0. Anal. Calcd for $C_{27}H_{22}N_2O_4$: C, 73.95; H, 5.06; N, 6.39, found C, 73.78; H, 5.11; N, 6.17.

Preparation and Rhodium(II)-Catalyzed Reaction of 5-(*N*-Allyl-*N*-phenylamino)-1-diazo-2,5-pentanedione (29). A solution containing 1.0 g (10 mmol) of succinic anhydride and 1.35 g (10.1 mmol) of *N*-allylaniline in 20 mL of THF was allowed to stir at rt for 1 h. Standard workup afforded 4-(*N*-allyl-*N*-phenyl-amino)-4-oxobutanoic acid as a clear oil (90%): IR (neat) 1736, 1718, 1660, 1600, and 708 cm^{-1}; ^{1}H NMR (90 MHz, $CDCl_3$) δ 2.35 (t, 2H, J = 6.0 Hz), 2.64 (t, 2H, J = 6.0 Hz), 4.31 (d, 2H, J = 6.2 Hz), 4.95−5.23 (m, 2H), 5.70−6.08 (m, 1H), 7.15−7.52 (m, 5H), and 9.90 (brs, 1H). This material was converted to α-diazo ketoamide **29** by the standard procedure in 74% yield: IR (neat) 2113, 1670, 1502, and 716 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.38 (t, 2H, J = 6.3 Hz), 2.60 (t, 2H, J = 6.3 Hz), 4.28 (d, 2H, J = 6.0 Hz), 5.07 (d, 1H, J = 17.1 Hz), 5.10 (d, 1H, J = 9.5 Hz), 5.32 (s, 1H), 5.84 (ddt, 1H, J = 17.1, 9.5, and 6.0 Hz), 7.21 (d, 2H, J = 7.5 Hz), and 7.29−7.46 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 28.6, 34.8, 51.6, 53.9, 117.1, 127.4, 127.7, 129.0, 132.4, 141.5, 170.4, and 193.2.

Treatment of 260 mg (1.01 mmol) of **29** with 2 mg of rhodium(II) acetate in 3 mL of $CHCl_3$ in the presence of 200 mg (1.04 mmol) of *N*-phenylmaleimide afforded 6-*trans*-(*N*-allyl-*N*-phenylcarbamyl)-4,5-*trans*-((*N*-phenylimino)dicarbonyl)-1-oxaspiro[2.4]heptane (58%) (**35**): mp 127−128 °C; IR (neat)

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1726, 1660, 1508, 1395, and 720 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.70 (dd, 1H, J = 14.4 and 6.8 Hz), 2.75 (dd, 1H, J = 14.4 and 11.2 Hz), 2.91 (d, 1H, J = 8.2 Hz), 2.94 (d, 1H, J = 4.0 Hz), 3.22 (dd, 1H, J = 10.0, and 8.2 Hz), 3.39 (ddd, 1H, J = 11.2, 10.0 and 6.8 Hz), 3.44 (d, 1H, J = 4.0 Hz), 4.27 (dd, 1H, J = 14.7 and 6.7 Hz) 4.37 (dd, 1H, J = 14.7 and 6.0 Hz), 5.05 (d, 1H, J = 16.9 Hz), 5.10 (d, 1H, J = 9.8 Hz), 5.92 (dddd, 1H, J = 16.9, 9.8, 6.7, and 6.0 Hz), and 7.29−7.53 (m, 10H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 35.0, 43.8, 46.1, 47.1, 50.8, 52.3, 64.6, 117.5, 126.0, 127.9, 128.0, 128.2, 128.6, 129.2, 131.1, 132.3, 141.1, 169.0, 173.6, and 174.9. Anal. Calcd for $C_{24}H_{22}N_2O_4$: C, 71.63; H, 5.51; N, 6.96, found C, 71.70; H, 5.52; N, 6.96.

The reaction of 260 mg (1.01 mmol) of **29** in 3 mL of $CHCl_3$ with 2 mg of rhodium(II) acetate in the absence of a dipolarophile afforded 6-(*N*-allyl-*N*-phenylamino)-2*H*-pyran-3(4*H*)-one (**44d**) in 72% yield as a labile oil: ^1H NMR (300 MHz, $CDCl_3$) δ 2.99 (d, 2H, J = 3.8 Hz), 4.19 (d, 2H, J = 5.0 Hz), 4.31 (s, 2H), 4.58 (t, 1H, J = 3.8 Hz), 5.16 (d, 1H, J = 10.4 Hz), 5.24 (d, 1H, J = 17.5 Hz), 5.89 (ddt, 1H, J = 17.5, 10.4, and 5.0 Hz), 6.96 (d, 2H, J = 8.4 Hz), and 7.18−7.31 (m, 3H). All attempts to obtain an analytically pure sample of **44d** failed as it was rapidly converted to dihydropyrandione **41**.

Preparation and Rhodium(II)-Catalyzed Reaction of 1-Diazo-5-(*N*-Methyl-*N*-(*p*-nitrophenyl)amino)-2,5-pentanedione (36). α-Diazo ketoamide **36** was prepared in 51% yield from 3.1 g (20.4 mmol) of *N*-methyl-4-nitroaniline and 2.1 g (21 mmol) of succinic anhydride followed by condensation with diazomethane as described above: IR (oil) 2105, 1665, 1517, and 1342 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 2.53 (brs, 2H), 2.69 (brs, 2H), 3.35 (s, 3H), 5.36 (s, 1H), 7.49 (d, 2H, J = 8.7 Hz), and 8.29 (d, 2H, J = 8.7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 28.3, 34.6, 36.7, 54.1, 124.4, 127.1, 145.7, 148.8, 170.5, and 192.8.

Treatment of a sample of **36** with 2 mg of rhodium(II) acetate afforded 6-(*N*-methyl-*N*-*p*-nitrophenyl)amino-2H-pyran-3(4H)-one (**37**) in 87% yield as a pale yellow oil; ^1H NMR (300 MHz, $CDCl_3$) δ 3.08 (d, 2H, J = 3.4 Hz), 3.25 (s, 3H), 4.43 (s, 2H), 4.95 (t, 1H, J = 3.4 Hz), 6.88 (d, 2H, J = 9.3 Hz), and 8.13 (d, 2H, J = 9.3 Hz). Anal. Calcd for $C_{12}H_{12}N_2O_4$: C, 58.05; H, 4.88; N, 11.29, found C, 57.97; H, 4.96; N, 11.04. This material was unreactive with DMAD and *N*-phenylmaleimide and failed to produce a cycloadduct. Over a period of time, it slowly decomposed to give dihydro-2*H*-pyran-2,5(3*H*)-dione (**41**) and *N*-methyl-4-nitroaniline.

Preparation and Rhodium(II)-Catalyzed Reaction of 1-Diazo-5-(*N*-(*p*-methoxyphenyl)-*N*-methylamino)-2,5-pentanedione (38). α-Diazo ketoamide **38** was prepared in 73% yield from 2.8 g (20.4 mmol) of *N*-methyl-*p*-anisidine and 2.1 g (21 mmol) of succinic anhydride followed by condensation with diazomethane as described above and was isolated as a yellow solid: mp 87−88 °C; IR (neat) 2112, 1740, 1647, 1515, and 850 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 2.38 (t, 2H, J = 7.4 Hz), 2.59 (t, 2H, J = 7.4 Hz), 3.22 (s, 3H), 3.83 (s, 3H), 5.34 (s, 1H), 6.92 (d, 2H, J = 8.6 Hz), and 7.15 (d, 2H, J = 8.6 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 28.3, 35.0, 36.8, 53.9, 54.8, 114.3, 127.8, 135.8, 158.3, 171.2, and 193.3. Anal. Calcd for $C_{13}H_{15}N_3O_3$: C, 59.76; H, 5.79; N, 16.08, found C, 59.80; H, 5.82; N, 15.98.

The reaction of 270 mg (1.03 mmol) of **38** with 2 mg of rhodium(II) acetate at rt in 3 mL of $CHCl_3$ for 30 min in the presence of DMAD afforded three products. The first fraction (15% yield) isolated from the silica gel column was assigned as dimethyl (*N*-(*p*-methoxyphenyl)-*N*-methylamino)-maleate (**40**): mp 106−107 °C; IR (KBr) 1736, 1686, 1562, and 790 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 3.14 (s, 3H), 3.60 (s, 3H), 3.64 (s, 3H), 3.76 (s, 3H), 4.70 (s, 1H), 6.82 (d, 2H, J = 9.0 Hz), and 7.09 (d, 2H, J = 9.0 Hz). Anal. Calcd for $C_{14}H_{17}NO_5$: C, 60.19; H, 6.14; N, 5.02, found C, 59.84; H, 5.88; N, 4.97.

The second fraction (15%) was identified as dihydro-2*H*-pyran-2,5(3*H*)-dione (**41**). The major fraction (49%) was a clear oil whose structure was assigned as 6-*trans*-((*N*-(*p*-methoxyphenyl)-*N*-methylamino)carbonyl)-4,5-dicarbomethoxy-1-oxaspiro[2.4]hept-4-ene (**39**): IR (neat) 1720, 1655, 1492, 1437, and 1130 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 2.01 (dd, 1H, J = 14.4 and 9.2 Hz), 2.37 (dd, 1H, J = 14.4 and 5.0 Hz), 2.99 (d, 1H, J = 4.5 Hz), 3.25 (s, 3H), 3.33 (d, 1H, J = 4.5 Hz), 3.75 (s, 3H), 3.78 (s, 3H), 3.84 (s, 3H), 4.14 (dd, 1H, J = 9.2 and 5.0 Hz), 6.94 (d, 2H, J = 8.4 Hz), and 7.17 (d, 2H, J = 8.4 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 33.5, 37.0, 45.7, 51.7, 52.4, 54.9, 66.7, 114.4, 127.9, 135.5, 140.1, 142.3, 158.5, 162.5, 163.0, and 171.7. Anal. Calcd for $C_{19}H_{21}NO_7$: C, 60.78; H, 5.64; N, 3.73, found C, 60.53; H, 5.45; N, 3.47.

The major product (46%) isolated from the rhodium(II)-catalyzed cycloaddition reaction of **38** with *N*-phenylmaleimide in dry $CHCl_3$ was identified as 4,5-*trans*-((*N*-phenylimino)-dicabonyl)-6-*trans*-(*N*-(*p*-methoxyphenyl)-*N*-methylamino)-1-oxaspiro[2.4]heptane (**42**): mp 165−166 °C; IR (KBr) 1721, 1640, 1509, and 1188 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.68 (dd, 1H, J = 14.5 and 6.9 Hz), 2.75 (dd, 1H, J = 14.5 and 11.5 Hz), 2.91 (d, 1H, J = 8.2 Hz), 2.96 (d, 1H, J = 4.0 Hz), 3.21 (dd, 1H, J = 9.6, and 8.2 Hz), 3.27 (s, 3H), 3.44 (d, 1H, J = 4.0 Hz), 3.47 (ddd, 1H, J = 11.5, 9.6 and 6.9 Hz), 3.85 (s, 3H), 6.96 (d, 2H, J = 8.7 Hz), and 7.30−7.52 (m, 7H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 34.8, 37.4, 43.6, 45.9, 47.0, 50.8, 54.9, 64.6, 114.4, 125.9, 128.0, 128.1, 128.5, 131.1, 135.5, 158.7, 169.5, 173.6, and 175.1. Anal. Calcd for $C_{23}H_{22}N_2O_5$: C, 67.97; H, 5.46; N, 6.89, found C, 67.86; H, 5.43; N, 6.85.

Preparation and Rhodium(II)-Catalyzed Reaction of *N*-Benzyl-3-(3′-diazo-2′-oxopropyl)-2-piperidone (53). To a solution containing 5.6 mL of diisopropylamine (44.4 mmol) and 27.7 mL of a 1.6 M *n*-butyllithium solution in hexane (44.4 mmol) at −78 °C in 150 mL of THF was added 7.0 g (37 mmol) of *N*-benzyl-2-piperidone.[55] The mixture was allowed to stir for 3 h and was then slowly warmed to 10 °C. The solution was recooled to −78 °C, and 14.2 mL (111.0 mmol) of allyl bromide was added. The solution was stirred at −78 °C for 2 h and was warmed to rt, and the reaction was quenched by the addition of a saturated NH_4Cl solution. The mixture was extracted with ether, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by silica gel chromatography to give 7.04 g (84%) of *N*-benzyl-3-allyl-2-piperidone (**52a**) as an amber oil: IR (neat) 2900, 1615, and 1475 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.40−1.95 (m, 4H), 2.25−2.50 (m, 2H), 2.65−2.80 (m, 1H), 3.17 (dd, 2H, J = 5.0 and 2.0 Hz), 4.60 (dd, 2H, J = 14.6 and 4.2 Hz), 5.00−5.25 (m, 2H), 5.70−5.95 (m, 1H), and 7.10−7.45 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.6, 26.0, 36.5, 41.3, 47.5, 50.3, 116.8, 127.2, 127.9, 128.5, 136.4, 137.4, and 171.9.

A solution containing 8.5 g (37.1 mmol) of the above compound in 100 mL CH_2Cl_2 at −78 °C was ozonized until a light blue color persisted. The mixture was flushed with oxygen to remove the excess ozone. The ozonide was warmed to 0 °C, and 14.0 mL (37.1 mmol) of Jones reagent was slowly added to the mixture. The solution was allowed to stir for 1 h, filtered to remove the chromium salts, and concentrated under reduced pressure. The residue was taken up in 50 mL of 1 N NaOH, washed twice with ether, and acidified to pH 2. The mixture was extracted with ether, dried over Na_2SO_4, and concentrated under reduced pressure to give 5.1 g (56%) of *N*-benzyl-2-piperidone ethanoic acid as a clear oil: IR (neat) 3419, 1717, and 1625 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.60−2.05 (m, 4H), 2.20−2.65 (m 1H), 3.26 (dd, 2H, J = 8.4 and 4.1 Hz), 2.75−2.90 (m, 2H), 4.60 (d, 1H, J = 14.6 Hz) 4.66 (d, 1H J = 14.6 Hz), and 7.05−7.45 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 22.0, 27.4, 37.4, 38.2, 47.5, 50.7, 127.6, 128.0, 128.7, 136.4, 172.8, and 175.7.

To a solution containing 1.5 g (6.1 mmol) of the above acid and 687 mg (7.3 mmol) of methyl chloroformate in 100 mL of ether was added 613 mg (6.06 mmol) of triethylamine. The resulting white suspension was stirred at rt for 1 h. The precipitated triethylamine hydrochloride was removed by filtration, and the colorless filtrate was immediately added to 40 mmol of freshly prepared diazomethane in ether at 0 °C. The mixture was allowed to warm to rt overnight, and the excess diazomethane was removed under reduced pressure. The resulting yellow oil was purified by silica gel chromatography to give 600 mg (37%) of *N*-benzyl-3-(3′-diazo-2′-oxopro-

(55) Magee, D. I.; Ramaseshan, M. *Synlett* **1994**, *9*, 743.

pyl)-2-piperidone (**53**) as a viscous yellow oil: IR (neat) 2944, 2118, 1822, and 1737 cm^{-1}; ^1H NMR ($CDCl_3$, MHz) δ 1.60−2.15 (m, 4H), 2.60 (dd, 1H, J =15.1 and 6.7 Hz), 2.80−3.05 (m, 2H), 3.23 (dd, 2H, J = 8.9 and 5.0 Hz), 4.47 (d, 1H, J = 14.6 Hz), 4.67 (d, 1H, J = 14.6 Hz), 5.32 (brs, 1H), and 7.20−7.45 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 22.4, 27.2, 39.0, 42.5, 47.3, 50.4, 54.9, 127.3, 127.9, 128.6, 137.2, 171.5, and 193.5.

To a 68 mg (0.25 mmol) sample of **53** in 5 mL of CH_2Cl_2 were added 42 mg (0.30 mmol) of dimethyl acetylenedicarboxylate and 2 mg of rhodium(II) acetate. The mixture was allowed to stir at rt for 1 h and was then concentrated under reduced pressure. The residue was subjected to flash chromatography on silica gel to give 24 mg (25%) of 10-benzyl-4,5-dicarbomethoxy-11-oxo-1-oxa-10-azadispiro[2.2.5.1]dodec-4-ene (**55**) as a colorless oil: IR (neat) 1714, 1626, and 1573 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.76−2.00 (m, 4H), 2.03 (d, 1H, J = 14.1Hz), 2.49 (td, 1H, J = 12.7 and 4.4 Hz), 2.84 (d, 1H, J = 14.1 Hz), 3.00 (d, 1H, J = 4.4 Hz), 3.32 (d, 1H, J = 4.4 Hz), 3.38 (dd, 2H, J = 11.8 and 5.1 Hz), 3.71 (s, 3H), 3.77 (s, 3H), 4.43 (d, 1H, J = 14.6 Hz), 4.75 (d, 1H, J = 14.6 Hz), and 7.20−7.40 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 20.6, 33.5, 43.2, 47.6, 50.9, 51.9, 52.3, 52.4, 55.3, 66.1, 127.4, 128.6, 128.6, 136.9, 142.3, 145.2, 163.0, 163.8, and 171.2; HRMS calcd for $C_{21}H_{23}NO_6$ 385.1526, found 385.1525.

The second fraction isolated from the column contained 53 mg (53%) of a yellow oil whose structure was assigned as *N*-benzyl-7,9a-dihydroxy-8,9-dicarbomethoxy-6-oxo-1-azabicyclo-[4.5]undec-8-ene (**57**): IR (neat) 2952, 1740, 1692, and 1572 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.20−1.75 (m, 5H), 2.45 (dd, 1H, J = 17.4 and 13.0 Hz), 2.62−2.81 (m, 2H), 3.13 (dd, 2H, J =7.3 and 6.8 Hz), 3.61 (s, 3H), 3.92 (s, 3H), 4.32 (s, 1H), 4.57 (d, 1H, J = 17.8 Hz), 4.70 (d, 1H, J = 17.8 Hz), and 7.20−7.40 (m 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 23.8, 26.8, 37.1, 39.3, 49.8, 50.8, 53.1, 54.0, 72.9, 85.3, 127.3, 127.9, 128.9, 135.4, 154.3, 166.1, 168.0, 171.3, and 203.2; HRMS calcd for $C_{21}H_{25}NO_7$ 403.1632, found 403.1631.

Preparation and Rhodium-Catalyzed Decomposition of *N*-Benzyl-3-(3′-diazo-2′-oxopropyl)-3-methyl-2-piperidone (58). To a solution containing 2.93 g (14.6 mmol) of *N*-benzyl-3-methyl-2-pipiridone in 50 mL THF at −78 °C was added 12 mL of 1.6 M *n*-butyllithium in hexane (16.1 mmol). The solution was warmed to 0 °C over a period of 4 h while stirring and then cooled to −78 °C. A 5.3 g (43.8 mmol) sample of allyl bromide was added, and the solution was allowed to warm to rt over 12 h. The reaction was quenched by the addition of a saturated NH_4Cl solution, and the solution was extracted with ether, washed with a saturated NaCl solution, and dried over $MgSO_4$. The mixture was concentrated under reduced pressure and purified by silica gel chromatography to give 1.65 g (47%) of 3-allyl-1-benzyl-3-methyl-2-piperidone (**52b**) as a pale yellow oil: IR (neat) 2920, 1620, and 1490 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.25 (s, 3H), 1.50−1.65 (m, 1H), 1.70−1.95 (m, 3H), 2.24 (dd, 1H, J = 13.6 and 8.1 Hz), 2.57 (dd, 1H, J = 13.6 and 6.7 Hz), 3.17 (t, 2H, J = 5.4 Hz), 4.50 (d, 1H, J = 14.6 Hz), 4.63 (d, 1H, J = 14.6 Hz), 5.05−5.10 (m, 2H), 5.75 (m, 1H), and 7.20−7.45 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 19.4, 25.9, 32.5, 41.6, 44.4, 47.8, 50.4, 118.0, 127.2, 127.9, 128.5, 134.6, 137.6, and 175.0.

A solution containing 0.15 g (0.74 mmol) of the above compound, 20 mL of methanol, and 3.75 mL of a 0.5 N methanolic NaOH solution at −78 °C was ozonized for 35 min.[56] A stream of oxygen was bubbled through the solution so as to remove the excess ozone. The solution was allowed to stir at 0 °C for 1 h, and the reaction was quenched by the addition of H_2O. The mixture was extracted with ether, washed with concentrated NaCl, and dried over $MgSO_4$. The solution was concentrated under reduced pressure, and the residue was purified by silica gel chromatography to give 97 mg (48%) of *N*-benzyl-3-(carbomethoxymethyl)-3-methyl-2-piperidone as a colorless oil: IR (neat) 2940, 1734, and 1635 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.31 (s, 3H), 1.60−2.05 (m, 3H), 2.10 (td, 1H, J = 12.7 and 3.5 Hz), 2.34 (d, 1H, J = 16.4 Hz), 3.10 (d, 1H, J = 16.4 Hz), 3.15−3.50 (m, 2H), 3.63 (s, 3H), 4.65 (bs, 2H) and 7.30 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 19.6, 26.6, 33.0, 40.2, 44.1, 47.6, 50.5, 51.3, 127.1, 128.0, 128.5, 137.5, 172.1, and 174.4.

To a 300 mg (1.09 mmol) sample of the above ester in 10 mL of ether was added 165 mg (1.31 mmol) of potassium trimethylsilanolate, and the mixture was heated at reflux for 12 h. The solution was cooled to 0 °C, and 0.16 mL (1.54 mmol) of methyl chloroformate was added. The resulting white suspension was allowed to warm to rt over a period of 4 h. The precipitate was filtered, and the filtrate was quickly added to 20 mmol of freshly prepared diazo-methane at 0 °C. The solution was allowed to warm to rt over a period of 12 h, and the excess diazomethane and ether were removed under reduced pressure. The mixture was purified by silica gel chromatography to give 192 mg (63%) of *N*-benzyl-3-(3′-diazo-2′-oxopropyl)-3-methyl-2-piperidone (**58**) as a bright yellow oil: IR (neat) 2099, 1699, and 1627 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.28 (s, 3H), 1.50−1.95 (m, 3H), 2.00−2.35 (m, 2H), 3.10−3.25 (m, 2H), 3.32 (td, 1H, J = 11.6 and 4.6 Hz), 4.49 (d, 1H, J = 14.7 Hz), 4.63 (d, 1H, J = 14.7 Hz), 5.26 (brs, 1H), and 7.20−7.45 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 19.6, 27.1, 32.8, 41.2, 47.8, 50.6, 55.3, 60.3, 127.2, 127.9, 128.5, 137.4, 174.4, and 193.3.

To a solution containing 27 mg (0.10 mmol) of the **58** and 17.5 μL (0.20 mmol) of dimethyl acetylenedicarboxylate in 10 mL of CH_2Cl_2 was added 5 mg of rhodium(II) acetate. Immediate nitrogen evolution was observed, and the solution was allowed to stir for an additional 2 h. The mixture was concentrated under reduced pressure to give (41%) of *N*-benzyl-7,9a-dihydroxy-8,9-dicarbomethoxy-6-oxo-1-azabicyclo[4.5]undec-8-ene (**61**): IR (neat) 3548, 1734, 1686, and 1565 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.24 (s, 3H), 1.40−1.60 (m, 4H), 2.48 (d, 1H, J = 16.5 Hz), 2.67 (d, 1H, J = 16.5 Hz), 3.00−3.20 (m, 2H), 3.62 (s, 3H), 3.92 (s, 3H), 4.30 (s, 2H), 4.66 (s, 1H), 4.69 (s, 2H), and 7.20−7.40 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 23.3, 26.9, 34.9, 40.8, 45.8, 49.8, 50.9, 53.1, 54.0, 72.4, 85.4, 127.3, 127.9, 128.9, 135.3, 154.3, 166.1, 168.0, 172.6, and 203.31; HRMS calcd for $C_{22}H_{27}NO_7$ 417.1785, found 417.1782.

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Supporting Information Available: ^{13}C NMR spectra for new compounds lacking analyses (3 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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