Rhodium(II)-Catalyzed Cyclization Reactions of Alkynyl-Substituted α-Diazo Ketones

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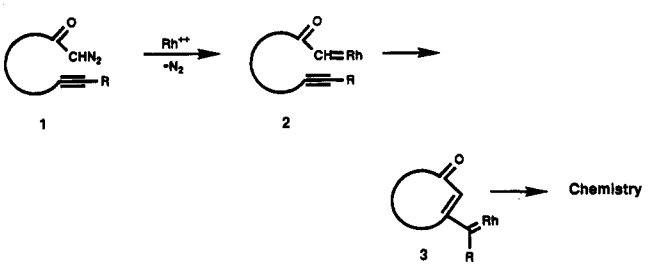
Treatment of several *o*-alkynyl-substituted α-diazoacetophenone derivatives with rhodium(II) carboxylates results in the formation of substituted indenones. The simplest mechanism accounting for the results involves addition of a rhodium-stabilized carbenoid onto the acetylenic π-bond to generate a vinyl carbenoid directly or possibly a highly strained cyclopropene derivative. The vinyl carbenoid was found to undergo addition to a neighboring alkene tethered on the side chain to give an indenyl-substituted bicyclo[3.1.0]hexane derivative. A number of related systems were examined so as to probe the scope and generality of the process. Treatment of *o*-(6,8-nonadien-1-ynyl)-α-diazoacetophenone with rhodium(II) mandelate afforded a cyclopent[*g*]azulenone derivative. The formation of this compound involves a divinylcyclopropane intermediate that readily undergoes a Cope rearrangement under the reaction conditions. The rhodium-catalyzed reaction of 2-(6-oxo-1-heptynyl)-α-diazoacetophenone in the presence of *N*-phenylmaleimide afforded a mixture of two cycloadducts. One of the products can be accounted for in terms of a cyclization of the vinyl carbenoid onto the oxygen atom of the neighboring carbonyl group to give a resonance-stabilized dipole. 1,3-Dipolar cycloaddition of the carbonyl ylide across the activated π-bond of *N*-phenylmaleimide affords the observed product. The second cycloadduct is formed by a 1,2-hydrogen shift of the initially produced vinyl carbenoid. The resulting diene undergoes a subsequent Diels–Alder reaction with *N*-phenylmaleimide.

A major challenge in organic synthesis today is to devise reactions that can form several carbon–carbon bonds in one operation leading to the construction of polycyclic structures with proper regio- and stereochemical control.[1] One of the more important pathways for assembling complex carbocyclic systems involves the intramolecular cyclopropanation of olefins.[2] Since the pioneering observation by Stork and Ficini in 1961,[3] intramolecular reactions of unsaturated α-diazo ketones have attracted considerable interest.[1-7] The mechanistic as well as the stereochemical aspects of carbon–carbon bond formation by this method have been studied in detail[8,9] and a vast array of experimental conditions for the generation of carbenes and carbenoids is offered through excellent reviews.[2-10] Elegant and practical examples of this reaction include the synthesis of gibberellin/gibberellic acid[11] and the triquinane sesquiterpenes.[12] By comparison, the intramolecular addition of diazo compounds to acetylenes is far less common. With the exception of an earlier report by Jones and Mykytka,[13] the catalytic internal cyclopropenation reaction of α-diazo keto alkynes is essentially unexplored. In our preliminary report,[14] we suggested that a carbenoid–alkyne *metathesis* reaction could produce a functional equivalent of a vinyl carbenoid, which might then lead to a variety of carbene-derived products including cyclic enones.[15-20] A related suggestion has been made by Hoye and co-workers.[21] Encouraged by our initial results,[14] we set out to define the generality and limitations of this approach to indenone derivatives. The present paper documents the results of these studies.



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Results and Discussion

In recent years much effort has been devoted to a study of the effect of different transition-metal catalysts on the decomposition of α-diazo carbonyl compounds.[4] The recent use of rhodium-based catalysts has produced major improvements in both intermolecular[22] and intramolecular cycloaddition of α-diazo carbonyls.[23] Rhodium(II) acetate is a dimer of $Rh(O_2CCH_3)_2$ containing a rhodium–rhodium single bond and four acetate ligands symmetrically attached to the two rhodium atoms.[24] Doyle has suggested that reactions catalyzed by rhodium(II) carboxylates can

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(16) Padwa, A.; Blacklock, T. J. *J. Am. Chem. Soc.* **1984**, *106*, 4446.
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(19) Newmann, M. F.; Buchecker, C. *Tetrahedron Lett.* **1973**, 2875.
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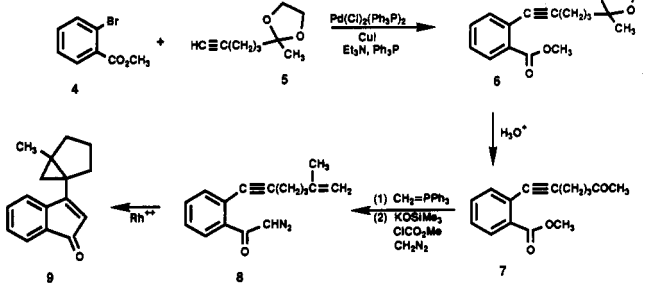
Scheme I

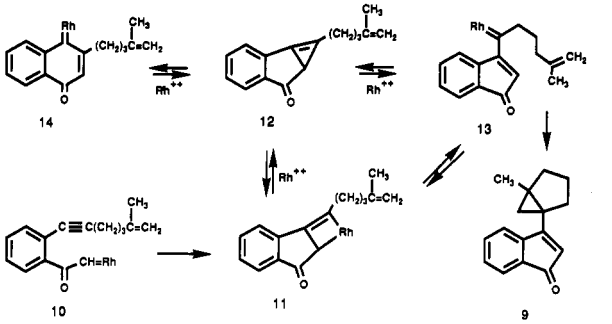


be viewed as taking place at the carbenic carbon, which protrudes from the metal embedded in a wall constructed from its ligands.[7] The rhodium(II)-catalyzed decomposition of α-diazo carbonyl compounds is believed to involve a metallo-carbenoid intermediate, which retains the highly electrophilic properties associated with free carbenes.[25] Therefore, in an appropriate acyclic substrate, such an intermediate can be intercepted intramolecularly by an adjacent acetylenic bond to effect overall cyclization.

Our initial results have focused on the rhodium(II)-catalyzed reaction of *o*-alkynyl-substituted α-diazoacetophenone derivatives. α-Diazo ketone **8** was prepared by first treating methyl *o*-bromobenzoate (**4**) with acetylene **5** under typical Castro–Stephens arylation conditions.[26] Hydrolysis of the ketal derived from the coupled product **6** afforded keto ester **7**. This material was readily converted to the desired α-diazo ketone by means of a Wittig reaction followed by treatment of the mixed anhydride with diazomethane (see Scheme I). Treatment of **8** with a catalytic quantity of rhodium(II) acetate at 25 °C in benzene afforded indenone **9** in 60% yield. This product was identified on the basis of its characteristic 300-MHz NMR spectrum ($CDCl_3$), which showed a set of doublets for the cyclopropyl hydrogens at δ 0.65 (J = 5.0 Hz) and 1.02 (J = 5.0 Hz), a singlet at 1.10 (3 H), multiplets centered at 1.4 (1 H), 1.8 (4 H), and 2.2 (1 H), a singlet at 5.67 (s, 1 H), and the aromatic protons at 7.0–7.4 (4 H); IR 1710 cm^{-1}.

Several rhodium(II) dimers with different electronic influences imparted on the rhodium(II) center by its ligands (i.e., octanoate, mandelate, trifluoroacetate) were prepared so as to evaluate their catalytic properties. The results obtained indicated very little difference in the yield of the rearranged product. We did find, however, that the more soluble rhodium mandelate was significantly more reactive than the acetate catalyst.

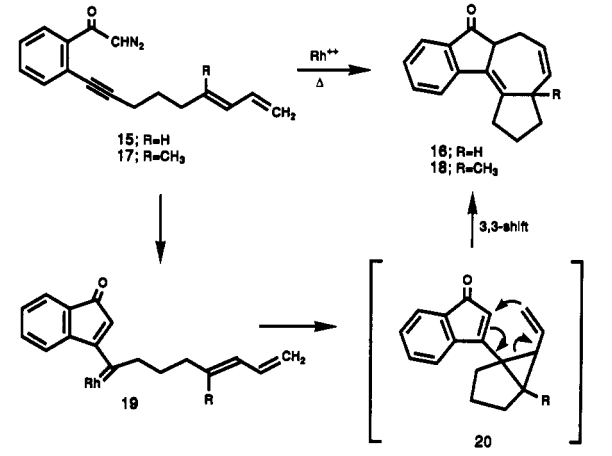
The simplest mechanism accounting for the results involves addition of a rhodium-stabilized carbenoid (i.e., **10**) onto the acetylenic π-bond to give vinyl carbenoid **13** directly. Alternatively, the highly strained cyclopropene derivative **12** may be formed. It is well known that cyclopropenes ring-open to vinyl carbenes at ambient temperatures[27] and that these reactive intermediates may be trapped by alkenes both in an inter-[28] and intramolecular fashion.[29] The exclusive formation of bicyclo[3.1.0]hexene



9 suggests that this product arises by either a regiocontrolled ring opening of **12** or is the result of a reversible process that involves selective trapping of intermediate **13**.

Very recently, we have discovered that these α-diazo keto alkyne insertion reactions are catalyst-dependent, thereby suggesting that a metalated species is involved in the product-determining step.[30] Similar observations have been made by Hoye.[21] One possibility is that the rhodium metal migrates from the original diazo carbon to the alkyne carbon via a metalated species such as **11**. Other possible variations are conceivable.[32] The highly strained cyclopropene **12** is probably rapidly converted into an organometallic species like **11**, **13**, or **14** under the reaction conditions.[31-33]

Since we were interested in exploiting the intramolecular alkyne insertion reaction of α-diazo ketones as a synthetic method, we carried out a number of experiments designed to probe the scope and generality of the process. Initial efforts focused on the rhodium(II)-catalyzed reaction of *o*-(6,8-nonadien-1-ynyl)-α-diazoacetophenone (**15**).



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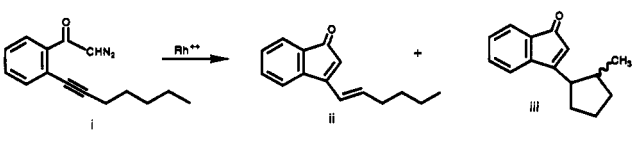
(30) Treatment of diazoalkyne i with rhodium(II) carboxylates affords a mixture of ii and iii: see ref 14. The ratio of the products was found to be markedly dependent on the nature of the carboxylate ligand. Full details will be given in a subsequent full paper.

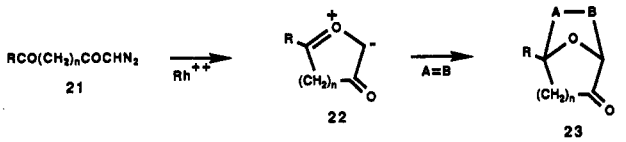


(31) Binger, P.; Buch, H. M. *Top. Curr. Chem.* **1987**, *135*, 77. Binger, P.; Muller, P.; Benn, R.; Mynott, R. *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 610.

Treatment of **15** with a catalytic quantity of rhodium(II) mandelate at 0 °C in methylene chloride afforded **16** in 58% yield. The NMR spectrum of **16** was a bit complicated, since a number of overlapping peaks were present. In order to simplify the spectrum, the reaction of the closely related diazo ketone **17** (R = CH_3) with rhodium(II) mandelate was carried out. The major product isolated (50%) corresponded to cyclopent[*g*]azulenone **18**.

The formation of the fused cycloheptadienes **16** and **18** can readily be rationalized by assuming that the reaction proceeds through a divinylcyclopropane intermediate (i.e., **20**). When the double bond nearest the tether is *E*-substituted, intramolecular cyclopropanation can only result in a *cis*-divinylcyclopropane, which would be expected to undergo a Cope rearrangement under very mild conditions. It should be noted that intramolecular cyclopropanation of dienes by simple carbenoids followed by rearrangement of the vinylcyclopropanes has been effectively utilized in synthesis.[34-42] The overall process is closely related to some earlier work of Davies, who developed a synthesis of fused seven-membered carbocycles based on a formal intramolecular [3 + 4]-cycloaddition of vinyl carbenoids with dienes.[43]

In earlier papers we have reported on the rhodium-induced α-diazo ketone cyclization onto a neighboring carbonyl group followed by dipolar cycloaddition of the resulting carbonyl–ylide dipole as a method for the formation of oxapolycyclic ring systems.[44] The ease with which



α-diazo ketones **21** undergo this tandem cyclization–cycloaddition reaction suggests that a similar sequence could also occur with a vinylogous keto carbene. In order to test this possibility, we studied the rhodium-catalyzed behavior of diazo ketone **24**. Treatment of **24** with a catalytic amount of rhodium(II) mandelate at 25 °C in benzene with

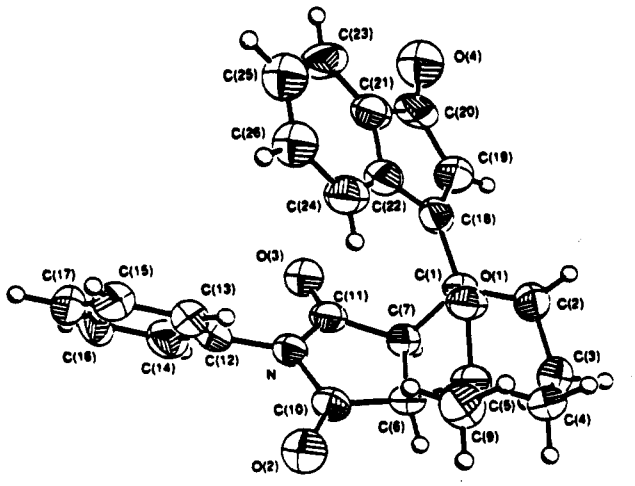
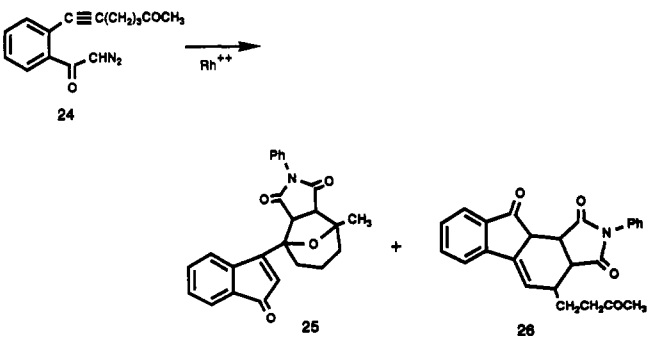


Figure 1. ORTEP drawing for 1-oxoinden-3-yl-8-methyl-4,8-epoxycyclohepta[*c*]pyrrole **25**.

Table I. Experimental Data for the X-ray Diffraction Study of 4-(1-Oxoinden-3-yl)-8-methyl-4,8-epoxycyclohepta[*c*]pyrrole

formula	$C_{25}H_{21}NO_4$
FW	399.1
crystal system	monoclinic
space group	$P2_1/C$
a, Å	7.0950 (25)
b, Å	15.0141 (34)
c, Å	18.7920 (41)
β	89.829 (24)
V, Å	1934.6 (5)
Z	4
D_{calcd}, g/cm^3	1.37
diffractometer	Syntex P2
crystal size	0.43 × 0.40 × 0.45 mm
radiation	Mo Kα with graphite monochromator
scan speed	2.0–24.0 deg/min in 2θ
data collected	$+h,+k,\pm l$
scan type	coupled θ(crystal)–2θ(counter)
scan width	($K\alpha_1$ – 1.0) to ($K\alpha_2$ + 1.1)
$2\theta_{max}$, deg	50.0
unique reflections	2919
reflections with $F^2 > 0$	1972
no. of variables	233
R_F	7.3
R_{wf}	7.5

N-phenylmaleimide afforded a 1:1 mixture of two compounds identified as cycloadducts **25** and **26**. The structure of cycloadduct **25** is based upon a detailed NMR analysis as well as on an X-ray crystallographic study. The



(32) Hoye and co-workers have recently found that the distribution of products arising from the rhodium(II)-catalyzed reaction of γ-diazo enones (i.e. **3**) differ from those obtained from the acetylenic diazo ketones (i.e. **2**). This result implies the lack of rhodium migration in the alkyne insertion reactions of **1**. Personal communication, T. Hoye (University of Minnesota).

(33) Products derived from a cyclohexenone related to **14** have recently been observed by Hoye and co-workers; see ref 21.

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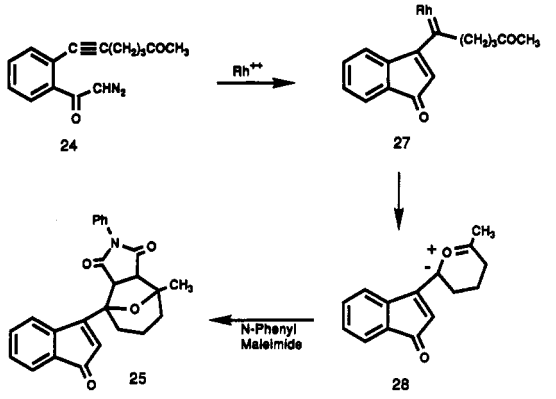
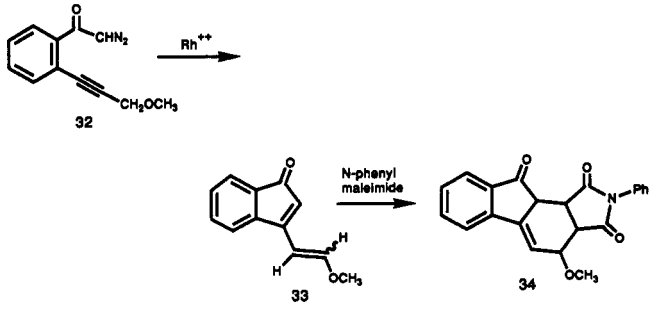
crystallographic details can be found in Table I and the final ORTEP diagram in Figure 1. The formation of **25** can nicely be accounted for in terms of the intermediacy of vinyl carbenoid **27**, which cyclizes onto the oxygen atom of the neighboring carbonyl group to give the resonance-stabilized dipole **28**. Dipolar cycloaddition of **28** across the activated π-bond of *N*-phenylmaleimide affords cycloadduct **25**.



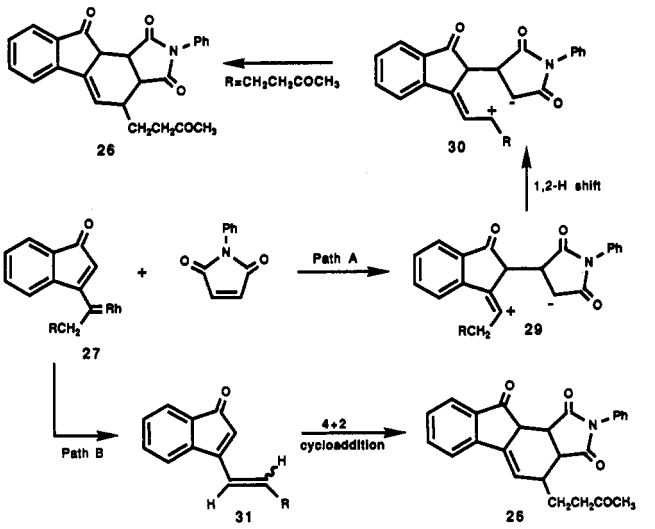
The mechanism by which α-diazo ketone **24** undergoes cycloaddition with *N*-phenylmaleimide to give trioxoindeno[2,1-*e*]isoindole **26** is of considerable interest. Two fundamentally different paths seem possible and these are presented in Scheme II. Path A is somewhat unique in that it involves nucleophilic addition of the vinyl carbenoid **27** onto the activated π-bond of *N*-phenylmaleimide, giving rise to zwitterion **29**. A 1,2-hydrogen shift producing the more stable charged species **30** would have to proceed at a faster rate than bond closure in order to account for the formation of **26**. The alternate path B involves an initial 1,2-hydrogen shift of vinyl carbenoid **27**, producing diene **31** as a transient species that then undergoes a subsequent Diels–Alder reaction with *N*-phenylmaleimide.

We have carried out a number of experiments designed to distinguish between these pathways. Our strongest evidence for path B comes from studies involving diazo ketone **32**. Treatment of **32** with rhodium(II) octanoate at 25 °C afforded a 2:1 mixture of (*E*) and (*Z*)-indenones **33** in 85% yield. The *Z* isomer was rapidly converted to the thermodynamically more stable *E* isomer upon standing at room temperature. Treatment of the *E*/*Z* mixture with *N*-phenylmaleimide at 25 °C afforded trioxoindeno[2,1-*e*]isoindole **34** in 60% isolated yield. This same material is formed by treating a mixture of diazo ketone **32** and *N*-phenylmaleimide with rhodium(II) octanoate.

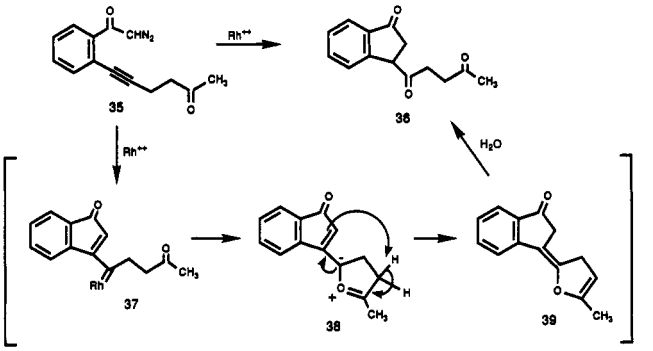


Extension of the carbenoid cyclization reaction of **24** to the homologous α-diazo keto system **35** was next investigated. The primary spatial requirement for carbonyl ylide formation is that the distance between the two reacting centers should be sufficiently close so that effective overlap of the lone pair of electrons on the carbonyl group with

Scheme II



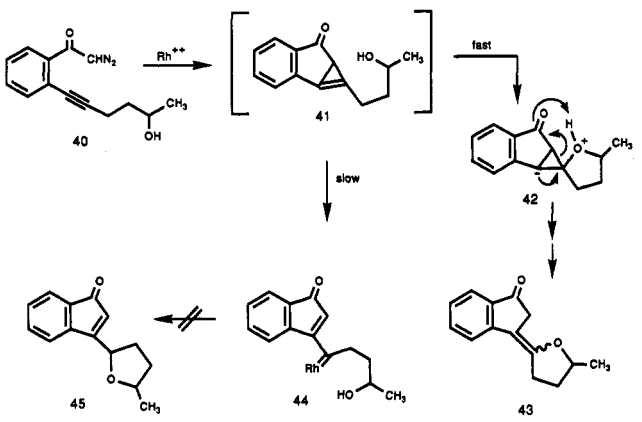
the metallocarbenoid center can occur. In view of the stringent spatial requirements associated with the process, we thought it worthwhile to consider what effect a variation in the spatial proximity between the diazo ketone and the carbonyl group would have on the course of the reaction. To this end we investigated the rhodium(II)-catalyzed reaction of diazo ketone **35** with *N*-phenylmaleimide and other trapping dipolarophiles (i.e., DMAD, methyl propiolate, benzaldehyde, etc.). In no case was it possible to isolate a cycloadduct derived from a carbonyl ylide intermediate. The only product formed (60%) corresponded to 3-(1,4-dioxo-1-pentyl)-1*H*-indanone (**36**). We



propose that the rhodium-catalyzed reaction of **35** proceeds through the intermediacy of **37** and carbonyl ylide **38**, which rapidly undergoes charge dispersal to produce enol ether **39** as a labile transient. One of the characteristic reactions of carbonyl ylides derived from the reaction of α-diazo alkanes with ketones consists of an intramolecular proton-transfer reaction to give enol ethers, thereby providing good precedent for the proposed sequence.[45-48] With this system, internal proton transfer from carbonyl ylide **38** to produce **39** is faster than bimolecular dipolar cycloaddition with an external dipolarophile. Rapid hydrolysis of **39** then produces the observed product **36**. In contrast, the additional methylene group present in diazo ketone **24** sufficiently retards the internal hydrogen-transfer process to allow that carbonyl ylide dipole (i.e. **28**) to undergo bimolecular cycloaddition.

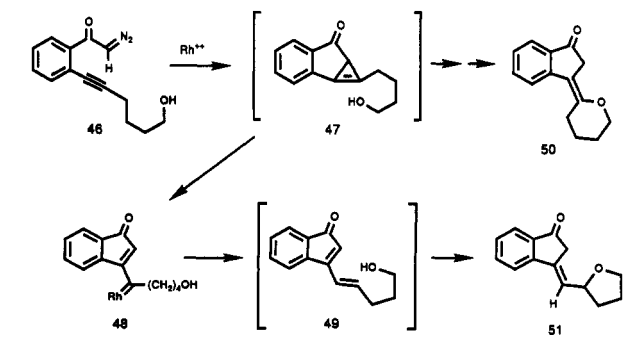
(45) Kharasch, M. S.; Rudy, T.; Nudenberg, W.; Buchi, G. *J. Org. Chem.* **1953**, *18*, 1030.
(46) Lottes, A.; Landrebe, J. A.; Larsen, K. *Tetrahedron Lett.* **1989**, 4089. Landgrebe, J. A.; Iranmanesh, H. *J. Org. Chem.* **1978**, *43*, 1244.
(47) Gutsche, C. D.; Hillman, M. *J. Am. Chem. Soc.* **1954**, *76*, 2236.
(48) Bien, S.; Gillon, A. *Tetrahedron Lett.* **1974**, 3073. Bien, S.; Gillon, A.; Kohen, S. *J. Chem. Soc., Perkin Trans. I* **1976**, 489.

We also investigated the possible insertion of the rhodium vinyl carbenoid into a neighboring alcohol functionality. In order to test for this possibility, we carried out a study dealing with the rhodium-catalyzed behavior of several o-hydroxyalkynyl substituted α-diazo ketones. The first compound investigated was 2-(5-hydroxy-1-hexynyl)-α-diazoacetophenone (**40**), which was prepared by treating methyl o-(bromophenyl)benzoate with the ethylene ketal of hex-1-yn-5-one under typical Castro–Stephens arylation conditions. The palladium-coupled



product was easily converted into **40** by using traditional methods. A sample of **40** was treated with rhodium(II) mandelate in benzene at 25 °C, producing a 4:1 *E*/*Z* mixture of indenylidenetetrahydrofuran **43** in 85% yield. No signs of product **45** derived from vinyl carbenoid insertion into the neighboring OH group could be detected in the crude reaction mixture. We believe that the exclusive formation of **43** can be accounted for in the following manner. Intramolecular addition of the rhodium-stabilized carbenoid onto the acetylenic π-bond may generate the highly strained cyclopropene **41**. This species is apparently too strained to survive at ambient temperature. Attack of the hydroxyl group onto the double bond would result in **42**, which rapidly undergoes ring cleavage to give **43**. In this case, intramolecular nucleophilic addition of the hydroxyl group on the cyclopropene ring is faster than ring opening to vinyl carbenoid **44**, which, if formed, would have produced indenone **45**.[49] The above results seem to imply the intermediacy of a transient cyclopropene in these rhodium-catalyzed transformations. However, further work is needed to clarify this point.

Attention was next turned to the rhodium-catalyzed behavior of the homologous diazo keto alcohol **46**. In this case, the rhodium(II)-catalyzed reaction afforded a 2:1 mixture of cyclic ethers **50** and **51** It would seem that



extension of the chain by one methylene unit sufficiently retards alcohol addition to the putative cyclopropene ring, thereby allowing a competing process to occur. In addition to trapping by the adjacent alcohol to form **50**, the initially formed cyclopropene **47** can also undergo ring opening to produce vinyl carbenoid **48**. Structure **51** is formed from **48** by way of a 1,2-hydrogen shift, producing diene **49**. This highly activated diene undergoes rapid internal conjugate addition, producing indenylidenetetrahydrofuran **51** in addition to pyran **50**.

In conclusion, the high efficiency of the intramolecular rhodium(II)-catalyzed cyclization reaction of alkynyl-substituted diazo ketones coupled with the simplicity of the procedure promises to provide an efficient route to a variety of substituted indenones. The question of the degree and nature of association of the metal atom with the alkyne in these reactions is of future interest. We are continuing to explore the scope and mechanistic details of these cyclization reactions and will report additional findings at a later date.

Experimental Section

Melting points are uncorrected. Mass spectra were determined at an ionizing voltage of 70 eV.

General Procedure for the Castro–Stephens Arylation Reaction. To a solution containing 1.0 mmol of the appropriate aryl halide and 1.0 mmol of the terminal alkyne in 40 mL of anhydrous triethylamine were added 5 mg of bis(triphenylphosphine)palladium(II) chloride, 10 mg of triphenylphosphine, and 10 mg of cuprous iodide.[50] The reaction mixture was placed in an oil bath and was heated at reflux for 16 h. The mixture was cooled to room temperature and was filtered. Removal of the solvent under reduced pressure followed by silica gel chromatography using a 25% ethyl acetate–hexane mixture as the eluent gave the coupled product in good yield.

General Procedure for the Preparation of α-Diazo Ketones from the Corresponding Methyl Ester. To a stirred solution containing 1 mmol of potassium trimethylsilanolate[51] in 15 mL of anhydrous ether was added, in one portion, the appropriate methyl benzoate. The reaction was stirred for 5 h at room temperature and was then heated at reflux for 2 h under a nitrogen atmosphere. After being cooled to 0 °C, 1.0 mmol of methyl chloroformate was added and the reaction mixture was stirred for 2 h at 25 °C. The mixture was filtered through Celite and a 3 mmol excess of an ethereal diazomethane solution was added. The resulting solution was stirred for 16 h at 25 °C and the excess diazomethane and ether were removed under reduced pressure. The residue was chromatographed on silica gel, using a 25% ethyl acetate–hexane mixture as the eluent to give the α-diazo ketone, which was used in the next step without further purification.

Preparation and Reaction of 2-(6-Methyl-6-hepten-1-ynyl)-α-diazoacetophenone (8) with Rhodium(II) Acetate. A solution containing 1.0 g of methyl 2-bromobenzoate (**4**) and 0.86 g of 6-heptyn-2-one ethylene ketal[52] (**5**) in 40 mL of anhydrous triethylamine was converted into 1.49 g (91%) of methyl 2-[5-(2-methyl-1,3-dioxan-2-yl)-1-heptynyl]benzoate (**6**): IR (neat) 2230, 1730, 1600, 1570, 1445, 1375, 1060, and 800 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.35 (s, 3 H), 1.74 (m, 2 H), 1.84 (m, 2 H), 2.50 (m, 2 H), 3.91 (s, 4 H), 3.95 (s, 3 H), 7.42 (m, 3 H), and 7.85 (m, 1 H).

To a solution containing 288 mg of the above benzoate and 1 mL of water in 10 mL of acetone was added 75 mg of pyridinium *p*-toluenesulfonate. The reaction mixture was heated at reflux for 3 h, after which time the solvent was removed under reduced pressure. The residue was dissolved in ether, washed with a saturated aqueous sodium bicarbonate solution and water, and then dried over magnesium sulfate. Removal of the solvent under

(49) The highly strained cyclopropene ring is known to readily undergo nucleophilic addition with alcohols; see: Hauck, G.; Durr, H. *J. Chem. Res.* **1981**, 180. Gardner, P. D.; Shields, T. C. *J. Am. Chem. Soc.* **1967**, *89*, 5425. Hashem, A.; Weyerstahl, P. *Tetrahedron* **1984**, *40*, 2003. Padwa, A.; Wannamaker, M. W.; Dyszlewski, A. D. *J. Org. Chem.* **1987**, *52*, 4760.

(50) Sabourin, T. E.; Onopchenko, A. *J. Org. Chem.* **1983**, *48*, 5135.
(51) Laganis, E. D.; Chenard, B. L. *Tetrahedron Lett.* **1984**, 5831.
(52) Sato, T.; Kohda, A.; Nagayoshi, K.; Maemoto, K. *J. Org. Chem.* **1983**, *48*, 425.

reduced pressure was followed by silica gel chromatography using a 25% ethyl acetate–hexane mixture as the eluent. The major fraction contained 225 mg of a yellow oil (92%), which was identified as methyl 2-(6-oxo-1-heptynyl)benzoate (7) on the basis of its spectral properties: IR (neat) 2250, 1750, 1720, 1600, 1570, 1360, 1045, and 760 cm^{-1}; NMR ($CDCl_3$, 90 MHz) δ 1.83 (qnt, 2 H, J = 7.5 Hz), 2.20 (s, 3 H), 2.51 (t, 2 H, J = 7.5 Hz), 2.70 (t, 2 H, J = 7.5 Hz), 3.93 (s, 3 H), 7.45 (m, 3 H), and 7.91 (m, 1 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 18.5, 22.0, 29.4, 41.5, 51.5, 79.5, 94.3, 123.7, 126.8, 129.6, 131.1, 131.4, 133.6, 166.1, and 207.8.

To a stirred solution containing 320 mg of methyl triphenylphosphonium bromide in 60 mL of anhydrous tetrahydrofuran was added 0.45 mL of a 2.0 M phenyllithium solution at 0 °C under a nitrogen atmosphere. The reaction was stirred for 1 h at 0 °C and then a solution containing 200 mg of benzoate 7 in 10 mL of tetrahydrofuran was added dropwise over 5 min and the reaction mixture was stirred for 14 h at room temperature. The mixture was diluted with 200 mL of ether, filtered, washed with a 10% hydrochloric acid solution followed by a saturated aqueous sodium bicarbonate solution and water, and then dried over magnesium sulfate. Removal of the solvent under reduced pressure was followed by silica gel chromatography using a 25% ethyl acetate–hexane mixture as the eluent. The major fraction contained 122 mg of a yellow oil (62%), which was identified as methyl 2-(6-methylhepten-1-ynyl)benzoate on the basis of its spectral properties: IR (neat) 2240, 1735, 1655, 1600, 1490, 1255, 1135, 765, and 710 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.73 (s, 3 H), 1.76 (dt, 2 H, J = 7.5 and 7.1 Hz), 2.19 (t, 2 H, J = 7.1 Hz), 2.47 (t, 2 H, J = 7.5 Hz), 3.90 (s, 3 H), 4.73 (s, 2 H), and 7.25–7.90 (m, 4 H).

A stirred solution containing 120 mg of the above benzoate was converted in the normal fashion to 100 mg of *o*-(6-methyl-6-hepten-1-ynyl)-α-diazoacetophenone (8): IR (neat) 2240, 2100, 1630, 1600, 1570, 765, and 710 cm^{-1}; NMR ($CDCl_3$, 90 MHz) δ 1.75 (s, 3 H), 1.80 (m, 2 H), 2.20–2.60 (m, 4 H), 4.70 (br s, 2 H), 6.20 (br s, 1 H), and 7.20–7.90 (m, 4 H).

A solution containing 250 mg of the above α-diazo ketone 8 in 50 mL of anhydrous benzene was treated with a catalytic amount of rhodium(II) acetate under a nitrogen atmosphere. After stirring for 30 min at 25 °C, the solvent was removed under reduced pressure and the residue was subjected to silica gel chromatography using a 25% ethyl acetate–hexane mixture as the eluent. The major fraction contained 150 mg of a yellow oil (60%), which was identified as 1-(1-oxo-1*H*-1-inden-3-yl)-5-methylbicyclo[3.1.0]hexane (9) on the basis of its spectral properties: IR (neat) 1710, 1610, 1560, 1490, 1090, and 770 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 0.65 (d, 1 H, J = 4.9 Hz), 1.02 (d, 1 H, J = 4.9 Hz) 1.09 (s, 3 H), 1.30–1.50 (m, 1 H), 1.70–2.05 (m, 4 H), 2.15–2.30 (m, 1 H), 5.67 (s, 1 H), and 7.05–7.45 (m, 4 H); UV (ethanol) 240 (ϵ 18770); HRMS calcd for $C_{16}H_{16}O$ 224.1201, found 224.1197. Anal. Calcd for $C_{16}H_{16}O$: C, 85.68; H, 7.19. Found: C, 85.42; H, 7.04.

Preparation and Reaction of *o*-(6,8-Nonadien-1-ynyl)-α-diazoacetophenone (15) with Rhodium Mandelate Dimer. A stirred suspension containing 3.53 g of lithium acetylide–ethylenediamine complex in 10 mL of dimethyl sulfoxide was cooled to 10 °C. To this mixture was added 7.0 g of 7-iodo-1,3-heptadiene[53] in 3 mL of dimethyl sulfoxide. The resulting suspension was stirred for 1 h at 10 °C and was then allowed to warm to 25 °C. After being stirred for an additional hour at room temperature, the mixture was quenched with ice–water and extracted with pentane. The pentane extracts were combined, washed with water, and dried over magnesium sulfate. Removal of the solvent under reduced pressure followed by distillation under reduced pressure (bp 54–55 °C (55 mm)) afforded 1.97 g of a colorless liquid (52%), which was identified as 1,3-nonadien-8-yne on the basis of its spectral properties: IR (neat) 2120, 1650, 1600, 1430, 1010, 950, and 905 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.62 (m, 2 H), 1.94 (t, 1 H, J = 2.4 Hz), 2.18 (m, 4 H), 4.95 (d, 1 H, J = 9.9 Hz), 5.09 (d, 1 H, J = 16.8 Hz), 5.66 (m, 1 H), 6.07 (dd, 1 H, J = 15.0 and 10.5 Hz), and 6.29 (dt, 1 H, J = 17.1 and 10.2 Hz).

(53) Vedejs, E.; Eberlein, T. H.; Wilde, R. G. *J. Org. Chem.* **1988**, *53*, 2220.

A mixture containing 1.13 g of methyl *o*-bromobenzoate (4) and 0.60 g of 1,3-nonadien-8-yne under the typical Castro–Stephens arylation conditions was converted into 1.01 g (80%) of methyl *o*-(6,8-nonadien-1-ynyl)benzoate: IR (neat) 2240, 1735, 1545, 1440, 1305, 1270, 1135, and 755 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.73 (m, 2 H), 2.27 (m, 2 H), 2.48 (t, 2 H, J = 7.2 Hz), 3.90 (s, 3 H), 4.96 (d, 1 H, J = 9.9 Hz), 5.08 (d, 1 H, J = 16.8 Hz), 5.71 (m, 1 H), 6.10 (dd, 1 H, J = 15.0 and 10.8 Hz), 6.30 (dt, 1 H, J = 10.2 and 16.8 Hz), 7.31 (t, 1 H, J = 8.1 Hz), 7.43 (t, 1 H, J = 7.5 Hz), 7.49 (d, 1 H, J = 7.5 Hz), and 7.86 (d, 1 H, J = 8.1 Hz); *m/e* (M+H) 255.

A 1.01-g sample of this ester was converted into 0.64 g (62%) of *o*-(6,8-nonadien-1-ynyl)-α-diazoacetophenone (15): IR (neat) 2250, 2130, 1620, 1485, 1360, 1010, 880, and 765 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.72 (m, 2 H), 2.27 (m, 2 H), 2.47 (t, 2 H, J = 6.9 Hz), 4.97 (d, 1 H, J = 10.2 Hz), 5.10 (d, 1 H, J = 16.5 Hz), 5.71 (m, 1 H), 6.10 (dd, 1 H, J = 14.9 and 10.8 Hz), 6.30 (m, 2 H), 7.39 (m, 3 H), and 7.67 (d, 1 H, J = 6.4 Hz).

To a solution containing 102 mg of diazo ketone 15 in 40 mL of methylene chloride at −25 °C was added 5 mg of rhodium mandelate. The reaction was stirred for 24 h at −25 °C and was then allowed to warm to room temperature. Removal of the solvent under reduced pressure was followed by silica gel chromatography of the residue using a 93:7 mixture of hexane–ethyl acetate mixture as the eluent. The major fraction contained 52 mg (58%) of a yellow oil, which was identified as 5,6,7,7a,10,10a-hexahydro-11*H*-benzo[*a*]cyclopent[*g*]azulen-9-one (16) on the basis of its spectral properties: IR (neat) 1710, 1600, 1470, 1265, 1050, 805, and 780 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.45–1.70 (m, 2 H), 1.95–2.04 (m, 2 H), 2.18 (m, 1 H), 2.71 (m, 2 H), 2.90 (m, 1 H), 3.46 (d, 1 H, J = 12.8 Hz), 3.65 (br s, 1 H), 5.52 (d, 1 H, J = 11.7 Hz), 5.63 (m, 1 H), 7.35 (t, 1 H, J = 7.5 Hz), 7.66 (m, 2 H), and 7.79 (d, 1 H< J = 7.5 Hz); HRMS calcd for $C_{17}H_{16}O$ 236.1201, found 236.1198. Anal. Calcd for $C_{17}H_{16}O$: C, 86.41; H, 6.82. Found: C, 86.29; H, 7.04.

Preparation and Reaction of *o*-(6-Methyl-6,8-nonadien-1-ynyl)-α-diazoacetophenone (17) with Rhodium(II) Mandelate Dimer. To a stirred solution containing 8.94 g of allyldiphenylphosphine oxide in 120 mL of tetrahydrofuran at −78 °C were added 14 mL of HMPA and 19.7 mL of a 1.6 M solution of *n*-butyllithium. The resulting red solution was stirred at −78 °C under a nitrogen atmosphere for 10 min, after which 6.02 g of methyl 2-(6-oxo-1-heptynyl)benzoate (7) was added over a 30-min period. The reaction was allowed to slowly warm to room temperature and was stirred for an additional 8 h. The reaction was quenched by pouring the solution into a dilute aqueous hydrochloric acid solution. The mixture was extracted with ether and the combined ether extracts were washed with brine, dried over magnesium sulfate, and concentrated under reduced pressure. The resulting residue was chromatographed on a silica gel column using a 25% ethyl acetate–hexane mixture as the eluent. The major fraction contained 3.0 g of a yellow oil (47%), which was identified as methyl *o*-(6-methyl-6,8-nonadien-1-ynyl)benzoate on the basis of its spectral properties: IR (neat) 1735, 1480, 1440, 1425, 1260, 1125, 895, and 755 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.74 (m, 2 H), 1.76 (s, 3 H), 2.24 (t, 2 H, J = 7.6 Hz), 2.46 (t, 2 H, J = 7.1 Hz), 3.88 (s, 3 H), 4.97 (d, 1 H, J = 10.5 Hz), 5.08 (d, 1 H, J = 16.8 Hz), 5.91 (d, 1 H, J = 10.5 Hz), 6.58 (ddd, 1 H, J = 16.8, 10.5, and 10.5 Hz), 7.30 (t, 1 H, J = 7.9 Hz), 7.42 (t, 1 H, J = 7.5 Hz), 7.49 (d, 1 H, J = 7.5 Hz), and 7.88 (d, 1 H, J = 7.9 Hz); HRMS calcd for $C_{18}H_{20}O_2$ 268.1463, found 268.1461.

A 130-mg sample of the above ester was converted into 87 mg (64%) of *o*-(6-methyl-6,8-nonadien-1-ynyl)-α-diazoacetophenone (17): IR (neat) 2105, 1610, 1350, 1205, 900, and 755 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.70–1.82 (m, 2 H), 1.75 (s, 3 H), 2.21 (t, 2 H, J = 7.5 Hz), 2.45 (t, 2 H, J = 7.1 Hz), 4.98 (d, 1 H, J = 10.6 Hz), 5.10 (d, 1 H, J = 16.8 Hz), 5.88 (d, 1 H, J = 10.9 Hz), 6.27 (s, 1 H), 6.56 (ddd, 1 H, J = 16.8, 10.9, and 10.6 Hz), 7.35 (m, 2 H), 7.45 (m, 1 H), and 7.65 (m, 1 H).

To an ice-cold solution containing 212 mg of diazo ketone 17 in 10 mL of methylene chloride was added 10 mg of rhodium mandelate. The solution was stirred for 3 h at 0 °C, and the mixture was allowed to slowly warm to room temperature. The solution was stirred for an additional 10 h at 25 °C, and the solvent was removed under reduced pressure. Purification of the crude residue by silica gel chromatography using a 9:1 hexane–ethyl

acetate mixture as the eluent gave 90 mg (50%) of a clear oil whose structure was identified as 5,6,7,7a,10,10a-hexahydro-7a-methylbenzo[a]cyclopent[g]azulen-9-one (18) on the basis of its spectral properties: IR (neat) 1720, 1605, 1475, 1270, and 780 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.28 (s, 3 H), 1.72–2.04 (m, 5 H), 2.64 (m, 1 H), 2.79 (m, 1 H), 2.97 (m, 1 H), 3.53 (dd, 1 H, J = 12.9 and 1.5 Hz), 5.58 (m, 2 H), 7.36 (t, 1 H, J = 7.5 Hz), 7.64 (t, 1 H, J = 7.8 Hz), 7.72 (d, 1 H, J = 8.1 Hz), and 7.80 (d, 1 H, J = 7.8 Hz); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.5, 26.3, 29.4, 33.1, 42.4, 47.8, 48.8, 123.1, 123.3, 124.5, 126.7, 128.4, 134.4, 135.1, 135.62, 148.5, 149.1, and 205.9; HRMS calcd for $C_{18}H_{18}O$ 250.1358, found 250.1358. Anal. Calcd for $C_{18}H_{18}O$: C, 86.36; H, 7.25. Found: C, 86.09; H, 7.11.

Preparation and Reaction of 2-(6-Oxo-1-heptynyl)-α-diazoacetophenone (24) with Rhodium(II) Mandelate Dimer. A 1.0-g sample of keto ester 7 was converted into 600 mg (58%) of 2-(6-oxo-1-heptynyl)-α-diazoacetophenone (24): IR (neat) 2240, 2110, 1715, 1620, 1355, and 760 cm^{-1}; NMR ($CDCl_3$, 90 MHz) δ 1.90 (m, 2 H), 2.20 (s, 3 H), 2.55 (m, 4 H), 6.16 (s, 1 H), 7.41 (m, 3 H), and 7.66 (m, 1 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 18.7, 22.1 29.7, 41.8, 56.6, 79.5, 95.5, 120.9, 127.5, 127.6, 130.6, 133.5, 139.0, 196.0, and 208.0.

A solution containing 240 mg of diazo ketone 24 and 540 mg of N-phenylmaleimide in 50 mL of anhydrous benzene was treated with a catalytic amount of rhodium(II) mandelate under a nitrogen atmosphere. After stirring for 30 min at 25 °C, the solvent was removed under reduced pressure, and the residue was subjected to silica gel chromatography using a 25% ethyl acetate–hexane mixture as the eluent. The first fraction isolated contained 190 mg of a yellow solid (48%), which was identified as decahydro-1,3-dioxo-4-(1-oxo-1H-inden-3-yl)-8-methyl-4,8-epoxycyclohepta[c]pyrrole (25) on the basis of its spectral properties: mp 271–272 °C; IR (CH_2Cl_2) 1725, 1395, 1215, 1205, and 850 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.55 (s, 3 H), 1.70–2.30 (m, 6 H), 3.35 (d, 1 H, J = 7.7 Hz), 3.70 (br d, 1 H, J = 7.7 Hz), 5.92 (s, 1 H), and 7.25 (m, 9 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 17.3, 23.1, 29.1, 33.1, 35.9, 52.1, 53.0, 121.6, 125.7, 128.1, 128.5, 130.9, 132.4, 142.3, 173.0, 174.1, and 196.3; UV (ethanol) 234 (ε 4400); HRMS calcd for $C_{25}H_{21}NO_4$ 399.1471, found 399.1461. Anal. Calcd for $C_{25}H_{21}NO_4$: C, 75.17; H, 5.30. Found: C, 75.04; H, 5.12. The X-ray structure of 25 was solved by direct methods using the SHELXTL program. Following anisotropic refinement of the skeleton atoms, all other hydrogen atoms were fixed into position. The final discrepancy index and weighted discrepancy index were R = 0.0727 and R_w = 0.0749, respectively. The final positional and thermal parameters are given in the supplementary section.

The second fraction contained 188 mg of a yellow solid (50%), which was identified as 1,2,3,3a,4,10,10a,10b-octahydro-4-(3-oxobutyl)-2-phenyl-1,3,10-trioxoindeno[2,1-e]isoindole (26) on the basis of its spectral properties: mp 250–251 °C; IR (CH_2Cl_2) 1720, 1620, 1520, 1390, 1200, 1025, and 815 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 2.10–2.30 (m, 2 H), 2.21 (s, 3 H), 2.65–2.98 (m, 3 H), 3.15 (br d, 1 H, J = 6.0 Hz), 3.51 (t, 1 H, J = 8.2 Hz), 4.05 (dd, 1 H, J = 8.2 and 6.0 Hz), 6.20 (m, 1 H), and 7.00–7.85 (m, 9 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 24.8, 29.5, 37.2, 40.9, 42.5, 43.5, 45.0, 120.6, 121.1, 123.7, 125.4, 127.9, 128.3, 129.1, 130.7, 134.2, 137.3, 138.1, 145.0, 174.1, 174.7, 199.3, and 207.5; UV ($CHCl_3$) 244 (ε 21 100); HRMS calcd for $C_{25}H_{21}NO_4$ 399.1471, found 399.1447. Anal. Calcd for $C_{25}H_{21}NO_4$: C, 75.17; H, 5.30. Found: C, 75.11; H, 5.09.

Preparation and Reaction of 2-(3-Methoxy-1-propynyl)-α-diazoacetophenone (32) with Rhodium(II) Octanoate and N-Phenylmaleimide. A degassed solution containing 5.24 g of methyl 2-iodobenzoate and 1.54 g of methyl propargyl ether in 100 mL of anhydrous triethylamine was coupled, using the general procedure outlined above, to give 3.11 g (76%) of methyl 2-(3-methoxy-1-propynyl)benzoate: IR (neat) 1730, 1595, 1570, 1360, 1190, 830, 760, and 705 cm^{-1}; NMR ($CDCl_3$, 90 MHz) δ 3.53 (s, 3 H), 3.83 (s, 3 H), 4.40 (s, 2 H), 7.20–7.60 (m, 3 H), and 7.80–8.00 (m, 1 H).

A 3.11-g sample of the above ester was converted in the usual fashion into 2.00 g (61%) of 2-(3-methoxy-1-propynyl)-α-diazoacetophenone (32): IR (neat) 2120, 1615, 1480, 1355, 1100, and 760 cm^{-1}; NMR ($CDCl_3$, 90 MHz) δ 3.50 (s, 3 H), 4.40 (s, 2 H), 6.20 (br s, 1 H), and 7.30–7.80 (m, 4 H).

A solution containing 200 mg of α-diazoacetophenone 32 and 490 mg of N-phenylmaleimide in 20 mL of anhydrous benzene was treated with a catalytic amount of rhodium(II) octanoate under a nitrogen atmosphere. After stirring for 24 h at room temperature, a solid precipitated out of the reaction mixture. The solid was washed with cold benzene to give 202 mg (60%) of material that was identified as 4-methoxy-1,2,3,3a,4,10,10a,10b-octahydro-2-phenyl-1,3,10-trioxoindeno[2,1-e]isoindole (34) on the basis of its spectral properties: mp 154–155 °C; IR (CH_2Cl_2) 1725, 1605, 1500, 1205, 1175, and 915 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 3.08 (d, 1 H, J = 8.4 Hz), 3.70 (s, 3 H), 3.88 (dd, 1 H, J = 8.3 and 5.5 Hz), 4.01 (dd, 1 H, J = 8.4 and 5.5 Hz), 4.47 (d, 1 H, J = 8.3 Hz), 6.38 (s, 1 H), 7.06–7.15 (m, 2 H), 7.20–7.37 (m 3 H), 7.40–7.50 (m, 1 H), 7.55–7.70 (m, 2 H), and 7.80–7.90 (m, 1 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 41.4, 43.6, 43.9, 57.8, 120.2, 121.0, 123.6, 125.5, 127.8, 128.3, 129.4, 130.8, 134.4, 136.0, 137.2, 194.9, 172.6, 173.9, and 199.2; HRMS calcd for $C_{22}H_{18}NO_4$ 359.1158, found 359.1156. Anal. Calcd for $C_{22}H_{18}NO_4$: C, 73.32; H, 5.03; N, 3.89. Found: C, 73.16; H, 4.91; N, 3.72.

A solution containing 30 mg of α-diazoacetophenone 32 in 0.6 mL of d_6-benzene in an NMR tube was treated with a catalytic amount of rhodium(II) octanoate. After 5 min, nitrogen evolution had ceased and a 300-MHz NMR spectrum of the crude reaction mixture indicated the complete disappearance of starting material and the formation of a 2:1 mixture of two inseparable dienes, which were identified as 3-((E)-2-methoxyethen-1-yl)-1-oxo-1H-indene (33E) and 3-((Z)-2-methoxyethen-1-yl)-1-oxo-1H-indene (33Z) on the basis of their spectral properties: IR (CH_2Cl_2) 1690, 1620, 1600, 1550, 1200, and 1085 cm^{-1}; NMR (C_6D_6, 300 MHz) major isomer (33E) δ 3.06 (s, 3 H), 5.47 (d, 1 H, J = 12.9 Hz), 5.71 (s, 1 H), 6.75–7.00 (m, 3 H), 7.02 (d, 1 H, J = 12.9 Hz), 7.50–7.60 (m, 1 H), minor isomer (33Z) δ 2.97 (s, 3 H), 5.17 (d, 1 H, J = 6.4 Hz), 5.92 (d, 1 H, J = 6.4 Hz), 6.59 (s, 1 H), 6.75–7.00 (m, 3 H), 7.50–7.60 (m, 1 H).

The mixture of dienes was treated immediately with 25 mg of N-phenylmaleimide at 25 °C for 40 min. A 300-MHz NMR spectrum indicated that all of the trans diene 33E had been consumed. Removal of the solvent under reduced pressure and chromatography of the brown residue on silica gel using a 25% ethyl acetate–hexane mixture as the eluent afforded 29 mg of material (60%), which was identified as 4-methoxy-1,2,3,3a,4,10,10a,10b-octahydro-2-phenyl-1,3,10-trioxoindeno-2,1-e]isoindole (34) on the basis of its spectral properties.

Preparation and Reaction of 2-(5-Oxo-1-hexynyl)-α-diazoacetophenone (35) with Rhodium(II) Mandelate. A mixture containing 15.3 g of methyl 2-bromobenzoate and 10.78 g of 5-hexyne-2-one ethylene ketal[54] in 150 mL of anhydrous triethylamine was coupled in the standard fashion to give 16.2 g (83%) of methyl 2-[5-(2-methyl-1,3-dioxan-2-yl)-1-butynyl]-benzoate: ^1H NMR ($CDCl_3$, 90 MHz) δ 1.36 (s, 3 H), 2.02 (t, 2 H, J = 9.0 Hz), 2.65 (t, 2 H, J = 9.0 Hz), 3.96 (s, 3 H), 4.02 (s, 3 H), 7.30–7.60 (m, 3 H), and 7.90–8.00 (m, 1 H).

A mixture containing 16.2 g of the above ketal, 5 g of pyridinium p-toluenesulfonic acid, 30 mL of water, and 500 mL of acetone was heated at reflux for 33 h. At the end of this time, the mixture was cooled and the solvent was removed under reduced pressure. The resulting residue was extracted with ether and the organic layer was washed with a 10% sodium bicarbonate solution and water and then dried over magnesium sulfate. Removal of the solvent and distillation of the residue under reduced pressure (bp 160 °C (0.5 mm)) left 12.4 g of a colorless oil (91%), which was identified as methyl 2-(5-oxo-1-hexynyl)benzoate on the basis of its spectral properties: bp 160 °C (0.5 mm); IR (neat) 2240, 1740, 1710, 1500, 1360, 1330, 1100, and 760 cm^{-1}; ^1H NMR ($CDCl_3$, 90 MHz) δ 2.21 (s, 3 H), 2.54–2.89 (m, 4 H), 3.93 (s, 3 H), 7.20–7.60 (m, 3 H), and 7.86–7.98 (m, 1 H).

A solution containing 2.3 g of the above keto ester was converted into 1.56 g (65%) of 2-(5-oxo-1-hexynyl)-α-diazoacetophenone (35): IR (neat) 2240, 2110, 1730, 1620, 1370, 930, 890, and 770 cm^{-1}; ^1H NMR ($CDCl_3$, 90 MHz) δ 2.21 (s, 3 H), 2.60–2.80 (m, 4 H), 6.33 (s, 1 H), 7.33–7.50 (m, 3 H), and 7.70–7.77 (m, 1 H).

A solution containing 240 mg of α-diazoacetophenone 35 in 20 mL of chloroform was treated with a catalytic amount of rhodium(II) mandelate under a nitrogen atmosphere. After stirring for 12 h at 25 °C, the solvent was removed under reduced pressure, and the residue was subjected to silica gel chromatography using

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a 30% ethyl acetate–hexane mixture as the eluent. The major fraction contained 219 mg of a white solid (60%), which was identified as 3-(1,4-dioxo-1-pentyl)-1*H*-indenone (**36**) on the basis of its spectral properties: IR (KBr) 1720, 1610, 1600, 1470, 1370, 1100, and 780 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.12 (s, 3 H), 2.71–2.81 (m, 4 H), 2.85 (dd, 1 H, J = 19.0 and 7.7 Hz), 2.96 (dd, 1 H, J = 19.0 and 3.6 Hz), 4.40 (dd, 1 H, J = 7.7 and 3.6 Hz), 7.39–7.43 (m, 1 H), 7.52–7.63 (m, 3 H), and 7.73 (d, 1 H, J = 7.6 Hz); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 29.2, 34.2; 36.4, 38.9, 50.5, 123.5, 125.9, 128.1, 134.4 136.1, 150.8, 203.5, 206.1, and 206.2. Anal. Calcd for $C_{14}H_{14}O_3$: C, 73.03; H, 6.13. Found: C, 73.04; H, 6.12.

Preparation and Reaction of 2-(5-Hydroxy-1-hexynyl)-α-diazoacetophenone (40) with Rhodium(II) Mandelate. To a stirred solution containing 4.6 g of methyl 2-(5-oxo-1-hexynyl)benzoate in 15 mL of methanol at 0–5 °C was added dropwise 250 mg of sodium borohydride in 10 mL of methanol. The mixture was slowly brought to room temperature and was stirred at 25 °C for 2 h. At the end of this time, 10 mL of a 10% hydrochloric acid solution was added to the mixture, and the solvent was removed under reduced pressure. The mixture was extracted with ether and the organic layer was washed with water and dried over anhydrous sodium sulfate. The solvent was removed under reduced pressure and the residue was chromatographed on a silica gel column using a 15% ethyl acetate–hexane mixture as the eluent. The major fraction contained 4.31 g of a light yellow oil (93%), which was identified as methyl 2-(5-hydroxy-1-hexynyl)benzoate on the basis of its spectral properties: IR (neat) 2220, 1720, 1490, 1430, 1300, 1130, 1090, 870, and 760 cm^{-1}; ^1H NMR ($CDCl_3$, 90 MHz) δ 1.21 (d, 3 H, J = 6.0 Hz), 1.84 (q, 2 H, J = 7.0 Hz), 2.56 (t, 2 H, J = 7.0 Hz), 3.25 (s, 1 H), 3.90 (s, 3 H), 4.03 (q, 1 H, J = 6.0 Hz), 7.20–7.50 (m, 3 H), and 7.80–7.90 (m, 1 H).

A solution containing 1.0 g of the above hydroxy ester was converted into 0.63 g (65%) of 2-(5-hydroxy-1-hexynyl)-α-diazoacetophenone (**40**): IR (neat) 2250, 2120, 1620, 1600, 1370, 930, 890, and 770 cm^{-1}; ^1H NMR ($CDCl_3$, 90 MHz) δ 1.26 (d, 3 H, J = 6.0 Hz), 1.78 (q, 2 H, J = 7.0 Hz), 2.30 (s, 1 H), 2.61 (t, 2 H, J = 7.0 Hz), 4.05 (q, 1 H, J = 6.0 Hz), 6.22 (s, 1 H), 7.30–7.50 (m, 3 H), and 7.66–7.77 (m, 1 H).

A solution containing 300 mg of α-diazoacetophenone **40** in 20 mL of dry dichloromethane was treated with a catalytic amount of rhodium(II) mandelate under a nitrogen atmosphere. After stirring for 6 h at 25 °C, the solvent was removed under reduced pressure, and the residue was subjected to silica gel chromatography using a 30% ethyl acetate–hexane mixture as the eluent. The first fraction contained 179 mg (68%) of a white solid, which was identified as 5-methyl-*trans*-2-(2,3-dihydro-1-oxo-1*H*-3-indenylidene)-2,3,4,5-tetrahydrofuran (**43E**) on the basis of its spectral properties: mp 86–87 °C; IR (KBr) 1710, 1690, 1460, 1190, 1090, 760, and 680 cm^{-1}; NMR ($CDCl_3$) δ 1.45 (d, 3 H, J = 6.1 Hz), 1.62–1.75 (m, 1 H), 2.15–2.37 (m, 1 H), 2.68–2.77 (m, 1 H), 3.09 (s, 2 H), 4.57–4.70 (m, 1 H), 7.18 (t, 1 H, J = 7.6 Hz), 7.55 (t, 1 H, J = 7.7 Hz), 7.70 (d, 1 H, J = 7.7 Hz), and 8.04 (d, 1 H, J = 7.6 Hz); HRMS calcd for $C_{14}H_{14}O_2$ 214.0994, found 214.0996. Anal. Calcd for $C_{14}H_{14}O_2$: C, 78.48; H, 6.59. Found: C, 78.32; H, 6.32.

The second fraction contained 44.8 mg of a yellow solid (17%), which was identified as 5-methyl-*cis*-2-(2,3-dihydro-1-oxo-1*H*-3-indenylidene)-2,3,4,5-tetrahydrofuran (**43Z**) on the basis of its spectral properties: mp 72–73 °C; IR (CH_2Cl_2) 1700, 1690, 1460, 1185, 1085, 1035, 965, and 850 cm^{-1}; NMR ($CDCl_3$) δ 1.38 (d, 3 H, J = 6.2 Hz), 1.70–1.87 (m, 1 H), 2.27–2.41 (m, 1 H), 2.85–2.97 (m, 1 H), 3.00–3.12 (m, 1 H), 3.24 (s, 2 H), 4.45–4.55 (m, 1 H), 7.18 (t, 1 H, J = 7.6 Hz), 7.41 (d, 1 H, J = 7.9 Hz), 7.53 (t, 1 H, J = 7.9 Hz), and 7.73 (d, 1 H, J = 7.6 Hz); HRMS calcd for $C_{14}H_{14}O_2$ 214.0994, found 214.0995. Anal. Calcd for $C_{14}H_{14}O_2$: C, 78.48; H, 6.59. Found: C, 78.23; H, 6.47.

Preparation and Reaction of 2-(6-Hydroxy-1-hexynyl)-α-diazoacetophenone (46) with Rhodium(II) Mandelate. A degassed solution containing 12.7 g of methyl 2-iodobenzoate and 5.0 g of 5-hexyn-1-ol in 400 mL of anhydrous triethylamine was coupled in the standard fashion to give 11.0 g (98%) of methyl 2-(6-hydroxy-1-hexynyl)benzoate: IR (neat) 2220, 1730, 1600, 1570, 1490, 1300, 1090, and 765 cm^{-1}; NMR ($CDCl_3$) δ 1.60–1.80 (m, 4 H), 2.25 (br s, 1 H), 2.50 (t, 2 H, J = 7.0 Hz), 3.65 (t, 2 H, J = 7.0 Hz), 3.90 (s, 3 H), 7.15–7.55 (m, 3 H), and 7.75–7.93 (m, 1 H).

A stirred solution containing 1.0 g of the above ester was converted into 1.63 g (58%) of 2-(6-hydroxy-1-hexynyl)-α-diazoacetophenone (**46**): IR (neat) 2240, 2110, 1615, 1360, 1055, 790, and 760 cm^{-1}; NMR ($CDCl_3$, 90 MHz) δ 1.50–1.80 (m, 4 H), 2.05 (br s, 1 H), 2.50 (t, 2 H, J = 6.8 Hz), 3.65 (t, 2 H, J = 6.8 Hz), 6.20 (br s, 1 H), 7.20–7.50 (m, 3 H), and 7.60–7.80 (m, 1 H).

A solution containing 224 mg of α-diazoacetophenone **46** in 25 mL of dry dichloromethane was added dropwise to a catalytic amount of rhodium(II) perfluorobutyrate in 5 mL of dry dichloromethane under a nitrogen atmosphere. After stirring for 30 min at 25 °C, the solvent was removed under reduced pressure, and the residue was subjected to silica gel chromatography using a 25% ethyl acetate–hexane mixture as the eluent. The first fraction contained 74 mg of a yellow oil (38%), which was identified as tetrahydro-2-(2,3-dihydro-1-oxo-1*H*-3-indenylidene)-2*H*-pyran (**50**) on the basis of its spectral properties: IR (neat) 1710, 1660, 1600, 1470, 1280, 910, 770, and 745 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 175–1.90 (m, 4 H), 2.35–2.45 (m, 2 H), 3.12 (s, 2 H), 4.10–4.20 (m, 2 H), 7.20–7.80 (m, 3 H), and 8.15–8.21 (m, 1 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 20.9, 24.1, 26.6, 39.2, 68.2, 108.4, 122.6, 123.3, 125.5, 125.7, 134.3, 149.4, 150.8, and 202.7; HRMS calcd for $C_{14}H_{14}O_2$ 214.0993, found 214.0991.

The second fraction contained 36 mg of a yellow oil (18%), which was identified as 2-[(2,3-dihydro-1-oxo-1*H*-3-indenylidene)methyl]-2,3,4,5-tetrahydrofuran (**51**) on the basis of its spectral properties: IR (neat) 1710, 1670, 1740, 1360, 925, 765, and 735 cm^{-1}; NMR ($CDCl_3$, 300 MHz) δ 1.60–1.80 (m, 1 H), 1.90–2.10 (m, 2 H), 2.11–2.22 (m, 2 H), 3.21 (d, 1 H, J = 21.9 Hz), 3.34 (d, 1 H, J = 21.9 Hz), 3.83 (dd, 1 H, J = 14.5 and 7.8 Hz), 3.97 (dd, 1 H, J = 14.5 and 7.2 Hz), 4.58 (dd, 1 H, J = 14.1 and 7.9 Hz), 6.26 (d, 1 H, J = 7.9 Hz), and 7.35–7.80 (m, 4 H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 25.6, 31.9, 38.9, 67.6, 76.2 (C_6D_6), 120.6, 122.9, 123.9, 128.3, 132.6, 134.1, 136.2, 149.5, and 201.8; HRMS calcd for $C_{14}H_{14}O_2$ 214.0993, found 214.0996.

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Supplementary Material Available: Final positional and thermal parameters of structure **25** and ^1H and ^{13}C NMR spectra (75 MHz) for all compounds with high resolution mass spectra (18 pages). Ordering information is given on any current masthead page.