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(31) The orbital-symmetry restrictions in pericyclic reactions might be removed by the action with certain transition metals.[32] However, such kind of perturbation has never been observed in the relevant dibromo ketone–iron carbonyl reactions; all reactions including the 3 + 4 → 7 cyclocoupling reaction (symmetry-allowed $[_{\pi}2_s + _{\pi}4_s]$ process),[17] nucleophilic trapping,[13] and various intramolecular rearrangements[13] can be understood without considering any special effects of iron atom or ions. We should like to emphasize a point that the present formally symmetry-restricted cycloaddition is also rationalized on the basis of our knowledge of ordinary organic chemistry.
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Novel Cyclopentenone Synthesis via the Iron Carbonyl Aided Cyclocoupling between α,α′-Dibromo Ketones and Enamines[1,2]

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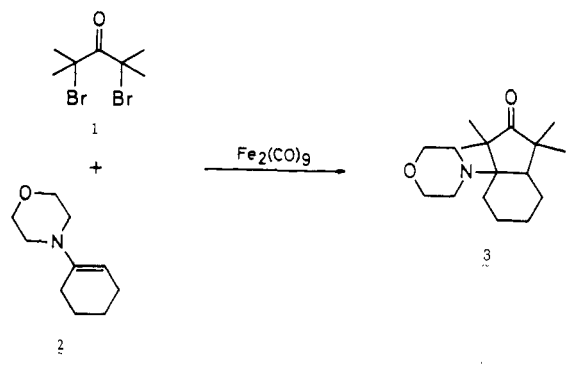
Abstract: Reaction of α,α′-dibromo ketones and morpholino enamines with the aid of iron carbonyls affords the corresponding 3-morpholinocyclopentanones. The adducts derived from secondary dibromo ketones and the enamines eliminate morpholine facilely, giving 2-cyclopentenones, and hence the coupling reaction provides a new, single-flask procedure for the preparation of five-membered ketones. This [3 + 2] cyclocoupling proceeds in high yield and finds a wide generality; the reaction with cyclic ketone enamines leads to bicyclo[*n*.3.0]alkenones, while the annelation using enamines of cycloalkanecarboxaldehydes gives rise to spiro[*n*.4]alkenone systems. The 7/5-fused bicyclic ketones obtained from 1-morpholinocycloheptene serve as a versatile intermediate for azulenoid synthesis.

Because cyclopentanoid derivatives are widely occurring in nature,[3] supply of a versatile and general tool for construction of five-membered ketones is very significant in synthetic chemistry. A large interest has been taken in this subject for a long time, and, as a result, a number of excellent synthetic methodologies have been elaborated.[4] This paper describes a novel, [3 + 2] type synthesis through the cyclocoupling between α,α′-dibromo ketones and enamines.

Results and Discussion

Cyclocoupling Reaction between α,α′-Dibromo Ketones and Enamines. A. Reaction with Tertiary Dibromide. Reaction of the dibromo ketone **1** and enamine **2** with the aid of $Fe_2(CO)_9$ (1.0:3.0:1.2 mole ratio) was performed in dry benzene. Usual extractive workup and chromatographic purification afforded the cycloadduct **3** in 87% yield. The structure of **3** was established by IR ($\nu_{C=O}$ 1732 cm^{-1}) and NMR analyses.



B. Reaction with Secondary Dibromides. Secondary dibromo ketones can be also employed for the cyclocoupling reaction. In this case the initially formed β-morpholinocyclopentanones have an active hydrogen atom at the position α to the carbonyl function and hence suffered readily elimination of morpholine, giving the unsaturated ketones. Thus various cyclopentenones can be prepared in the single-flask procedure according to Scheme I. The deamination of the initial β-morpholinocyclopentanone adducts [IR 1730–1740 cm^{-1} (C=O)], as usual, took place during chromatography on silica gel. When the α substituent R is bulky, for example, when R is isopropyl group, the elimination was not made sure by the silica gel treatment. In such a case, this purpose could be attained just by brief treatment with 3% ethanolic NaOH solution.

This cyclocoupling reaction has a wide generality. As enamines, those derived from either linear or cyclic ketones are employable. Enamines of aldehydes may be used as well. Examples of the reaction are given in Table I. As the solvent, benzene afforded the adduct in the highest yield. Use of other solvents such as tetrahydrofuran (THF) and *N,N*-dimethylformamide (DMF) gave no or little cyclocoupling products. As reducing agent iron pentacarbonyl in benzene might be also used but less effectively. Neither α,α′-dibromo-

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Table I. Iron Carbonyl Promoted Cyclopentenone Synthesis

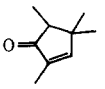
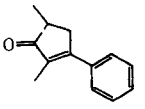
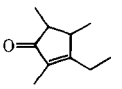
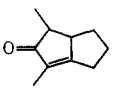
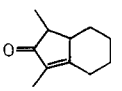
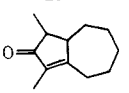
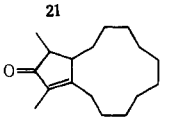
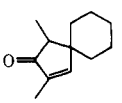
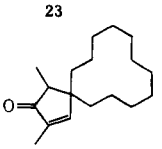
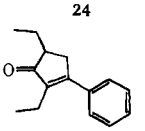
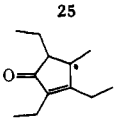
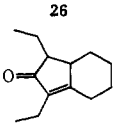
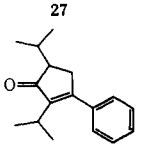
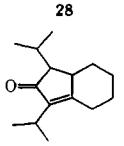
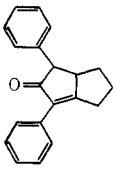
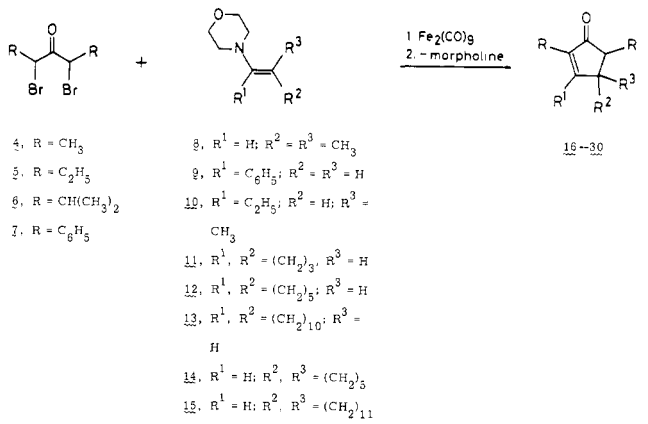
Dibromide, wt, mg (mmol)	Enamine, wt, mg (mmol)	Cycloadduct	Yield[a] wt, mg (%)	IR absorption in CCl_4, cm^{-1} $\nu_{C=O}$ and $\nu_{C=C}$	UV absorption in C_2H_5OH, nm (log ϵ)
4, 242(1.0)	**8**, 345(2.4)	 **16**	109 (79)[b]	1705 and 1640	231 (3.75)
4, 2440 (10.0) 24 400 (100)[c]	**9**, 4500 (21.0) 56 800 (300)[c]	 **17**	1680 (91) 15 600 (84)[c]	1696 and 1626	220 (3.72), 279 (4.05)
4, 244 (1.0)	**10**, 465 (3.0)	 **18**	111 (73)	1698 and 1641[d] 1700 and 1644[e]	241 (4.16)[d] 239 (4.09)[e]
4, 242 (1.0)	**11**, 510 (3.3)	 **19**	111 (74)	1704 and 1666[d] 1702 and 1665[e]	240 (3.99)[d] 240 (4.20)[e]
4, 1950 (8.0)	**2**, 5100 (31)	 **20**	1320 (100)	1700 and 1653[d] 1698 and 1653[e]	241 (4.10)[d] 240 (4.12)[e]
4, 244 (1.0)	**12**, 510 (2.8)	 **21**	180 (100)	1695 and 1634[d] 1695 and 1636[e]	242 (4.14)[d] 242 (4.14)[e]
4, 244 (1.0)	**13**, 505 (2.0)	 **22**	223 (90)	1697 and 1640[d] 1698 and 1642[e]	242 (4.14)[d] 242 (3.96)[e]
4, 244 (1.0)	**14**, 544 (3.0)	 **23**	128 (71)[b]	1706 and 1640	235 (3.76)
4, 244 (1.0)	**15**, 400 (1.5)	 **24**	164 (65)	1703 and 1639	232 (4.03)
5, 272 (1.0)	**9**, 535 (2.7)	 **25**	130 (64)	1695 and 1625	221 (3.86), 278 (4.23)
5, 272 (1.0)	**10**, 465 (3.0)	 **26**	126 (70)	1695 and 1638[d] 1696 and 1639[e]	239 (4.08)[d] 239 (4.09)[e]
5, 272 (1.0)	**2**, 510 (3.1)	 **27**	170 (89)	1696 and 1646[d] 1694 and 1649[e]	241 (4.17)[d] 239 (4.12)[e]
6, 510 (1.7)	**9**, 963 (5.1)	 **28**	293 (72)[b]	1690 and 1621	222 (3.82), 271 (4.11)
6, 510 (1.7)	**2**, 918 (5.5)	 **29**	274 (73)[b,f]	1693 and 1640[d]	241 (4.11)

Table I (*Continued*)

Dibromide, wt, mg (mmol)	Enamine, wt, mg (mmol)	Cycloadduct	Yield[a] wt, mg (%)	IR absorption in CCl_4, cm^{-1} $\nu_{C=O}$ and $\nu_{C=C}$	UV absorption in C_2H_5OH, nm (log ε)
7, 368 (1.0)	11, 510 (3.3)	 30	182 (66)[b,f]	1693 and 1641[d,g]	231 (4.23), 266 (4.04)

[a] Isolated yield of a mixture of trans and cis isomers based on starting dibromide. [b] Usual workup and TLC on silica gel often gave a β-morpholinocyclopentanone. [c] An example of the large-scale reaction. [d] Trans isomer. [e] Cis isomer. [f] A single trans isomer was obtained. [g] Determined in $CHCl_3$ solution.

Scheme I



4, R = CH_3
5, R = C_2H_5
6, R = $CH(CH_3)_2$
7, R = C_6H_5

8, R^1 = H; R^2 = R^3 = CH_3
9, R^1 = C_6H_5; R^2 = R^3 = H
10, R^1 = C_2H_5; R^2 = H; R^3 = CH_3
11, R^1, R^2 = $(CH_2)_3$; R^3 = H
12, R^1, R^2 = $(CH_2)_5$; R^3 = H
13, R^1, R^2 = $(CH_2)_{10}$; R^3 = H
14, R^1 = H; R^2, R^3 = $(CH_2)_5$
15, R^1 = H; R^2, R^3 = $(CH_2)_{11}$

16–30

nor α,α,α′,α′-tetrabromoacetone could be used in the present cyclocoupling reaction. The reaction of **4** and **2** in the presence of zinc–copper couple in 1,2-dimethoxyethane (DME) (at −5 °C for 30 min and at 25 °C for 16 h) gave **20** in 39% yield. The cyclocoupling reaction could not be accomplished by NaI as reducing agent.

Structural Determination of the 2-Cyclopentenone Products. All cyclopentenones listed in Table I showed strong IR absorptions at 1690–1710 (C=O) and 1620–1660 cm^{-1} (C=C).[5] In the UV spectra, 3-alkylcyclopentenones exhibited a 239–242-nm band and 3-unsubstituted ones showed a 230–235-nm absorption, respectively.[6] The mass spectra gave correct molecular peaks in all cases. The NMR spectra were also consistent with the 2-cyclopentenone structure.

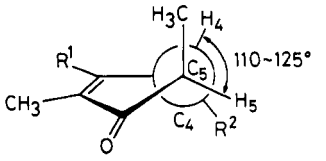
The cyclopentenones were produced as a mixture of diastereomers, when possible, and the isomers were separated by gas chromatography. These were interconvertible to each other by mild basic treatment (3% ethanolic NaOH solution). In a crude product (without the base or silica gel treatment), the more stable trans isomers (vide infra) were always present predominantly. The stereochemical relationship between the C_4 and C_5 substituents of the 2-cyclopentenones was determined by NMR analysis. Measurement of the H_4– H_5 coupling constants and the comparison with the values estimated from the Karplus equation[7] differentiate these stereochemistries. Inspection of Dreiding models revealed that the 2,5-dimethylcyclopentenone derivatives, **18** and **20–22,** have the favored conformation **31** in the trans isomer and **32** in the cis form, respectively. As visualized by the Newman diagram, **31** has an H_4/H_5 dihedral angle of 110–125° that corresponds to the coupling constant of 2.3–5 Hz, while **32** has the dihedral angle of 0–20° correlating to the coupling constant of 6.8–8 Hz. In actuality, the coupling constants are 2–3 Hz in the trans isomers[6,8,9] and 6–7 Hz in the cis derivatives, respectively.

Table II. Spin–Spin Coupling between H_4 and H_5 of 2-Cyclopentenones

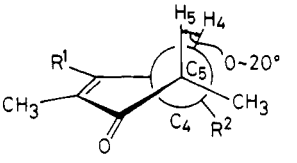
Cyclopentenone	Dihedral angle, deg	Coupling constant, Hz Calcd[a]	Found
trans-**18**	110–120	2.3–4.0	2.5
cis-**18**	0–15	7.2–7.9	7.0
trans-**19**	120–150	7.9–8.5	3.0[b]
cis-**19**	10–20	6.8–7.5	7.0[b]
trans-**20**	115–125	3.4–5.0	3.0[b]
cis-**20**	0–20	6.8–7.9	6.0[b]
trans-**21**	110–120	2.3–4.0	*c*
cis-**21**	0–15	7.2–7.9	7.5
trans-**22**	110–120	2.3–4.0	2.0
cis-**22**	0–15	7.2–7.9	*c*

[a] Calculated from the Karplus equation. [b] Determined by the $Eu(fod)_3$-aided NMR spectrum. [c] Not determined.

Thus, as summarized in Table II, the observed vicinal coupling constants fit well with the expected values. The stereochemistry



31

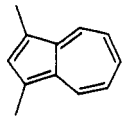


32

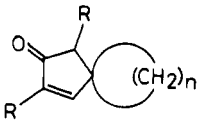
of other substituted cyclopentenones was confirmed in the same manner. However, for the cyclopentenone **19,** the NMR method is unreliable in assigning the stereochemistry.[10] Instead, in this case, relative stabilities of the two isomers gave definite evidence for their structures; in the 2,4-dialkylbicyclo[3.3.0]oct-1-en-3-one derivatives, isomers having trans H_4/H_5 relationship are the more stable[9] and the major isomer was assigned as *trans*-**19** and the other as *cis*-**19.**

Synthetic Utility and Applications. The iron carbonyl promoted cyclocoupling between secondary dibromo ketones and enamines opened a new, general route to α,α′-dialkylated cyclopentenones. The attractive features include the ready availability of the starting materials and operational simplicity. The advantages may be offset to some extent by the incapability of preparing the derivatives without α alkyl groups. This feature, however, would be rather a virtue of this method in view of the difficulty in introducing alkyl groups (particularly, bulky ones) to α positions of five-membered ketones.[11]

The reaction with the cycloalkanone enamines and secondary dibromo ketones leads efficiently to bicyclic cyclopentenones, where the second ring size can be changed arbitrarily. The 5/7-fused bicyclic ketones prepared from dibromo ketones and cycloheptanone enamine are powerful intermediates for the synthesis of azulenes. For instance, the adduct **21** could be easily converted to 1,3-dimethylazulene (**33**). Reduction of **21**



33



23, n = 5; R = CH_3

24, n = 11; R = CH_3

with $NaBH_4$ in ethanol was followed by dehydrogenation by heating with sulfur at 290–300 °C for 12 min,[12] giving **33** in 28% overall yield. A tedious multistep route has been required for the previous preparation of the bicyclo[5.3.0]decane system, the basic skeleton of azulenes.[13] By contrast, utilization of the present cyclocoupling reaction can construct the bicyclic skeleton directly, thereby making the azulene synthesis much more facile.

The second example which shows the utility of the cyclocoupling reaction is the convenient synthesis of spiro[*n*.4]-alkenone systems. For example, the reaction of **7** and enamines of cyclohexane- and cyclododecanecarboxaldehyde, **14** and **15,** gave the spiro-fused cyclopentenone derivatives **23** and **24** in 71 and 65% yields, respectively. This spiro-annelation finds a wider generality in comparison with the existing methods.[14] The lack of generality in the previous methods mainly arises from the limitation of source of starting materials and the number of carbons constructing the ring was forcibly subjected to restriction. By contrast, this spiro-annelation uses as starting material enamines which can be prepared easily from cycloalkanecarboxaldehydes and can select the ring size flexibly. Furthermore, the choice of the starting dibromide can introduce the optional substituent R into the cyclopentenone skeleton.

Reaction Course of the [3 + 2] Cyclocoupling Reaction. The preceding paper[1] described the iron carbonyl promoted reaction of dibromo ketones and arylated olefins, which leads to 3-arylcyclopentanones. The aryl group plays a crucial role in stabilizing the zwitterionic intermediate formed from reactive 2-oxyallyl species and the olefinic substrate. As shown in Scheme II, heteroatom substituted olefins can also serve as the receptor of the oxyallyl species **34,** because a great stability of the intermediate **35** is obtained by resonance involving a nonbonding electron pair of the heteroatom. The present reaction with enamines is its typical example [Y = $N(CH_2CH_2)_2O$].

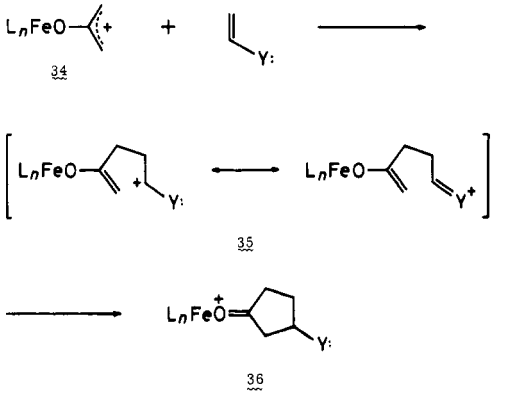
In the absence of the reducing agents, the dibromo ketone **4** and enamine **2** do not react under the present thermal conditions (25 °C, 24 h); the starting materials are recovered. On the other hand, when the mixture was treated with $Fe_2(CO)_9$, the cyclopentenone **20** was obtained in 100% yield. The reaction in furan solvent [**4, 2,** $Fe_2(CO)_9$, and furan in a 1.0:3.1:1.2:35 mole ratio] led to a 1:9 mixture of the enamine [3 + 2] adduct and furan [3 + 4] adduct.[15] These findings indicate clearly that both 3 + 2 → 5 and 3 + 4 → 7 cyclocoupling reactions[15] are proceeding through a common oxyallyl-Fe(II) intermediate.[16] The possibility that the [3 + 2] cyclocoupling reaction goes through an initial S_N2 type reaction of dibromo ketones and enamines[9,17] and subsequent iron carbonyl aided cyclization is excluded.

Attempted reaction of 2,2-dimethylcyclopropanone and the enamine **2** did not produce any cyclopentanone adducts.

Experimental Section

General. Melting points determined on a hot-stage apparatus are uncorrected. Nuclear magnetic resonance (NMR) spectra were recorded on either a JEOL Model C-60H or a Varian HA-100D instrument. Infrared (IR) spectra were taken on a JASCO Model DS-402G spectrometer. NMR and IR spectral data were obtained in CCl_4 solution unless otherwise noted. Ultraviolet (UV) spectra in ethanol solution were measured on a Perkin-Elmer Model 202 or a Hitachi Model 323 spectrophotometer. Low-resolution mass spectral

Scheme II



data were obtained at an ionization potential of 70 eV on a Hitachi RMU-6C instrument. A molecular peak and prominent fragment peaks are reported. Microanalyses were executed at the Analytical Center of Meijo University, Microanalytical Center of Kyoto University, Faculty of Engineering of Nagoya University, Research Laboratory of Fujisawa Pharmaceutical Co., and Chemical Research Laboratory of Takeda Pharmaceutical Co.

Chromatography. Analytical thin layer chromatography (TLC) was performed using a 3 × 10 cm glass slide coated with 0.25-mm thickness of E. Merck Kieselgel GF_{254}. For preparative work a 20 × 20 cm glass plate coated with 1.0-mm thick layer of silica gel PF_{254} (E. Merck) was utilized. Mallinckrodt silica gel (100 mesh) and E. Merck Kieselgel 60 (70–230 mesh) were used for column chromatography. For the alumina column, Woelm basic alumina (activity I) was used. Analytical gas–liquid phase chromatography (GLC) was conducted on a Hitachi 063 gas chromatograph with a flame ionization detector using nitrogen carrier. A column packed with 14% Silicone SE 30 on Chromosorb W AW (3 mm × 1 m) was employed. Preparative GLC was carried out on a Varian Model 1700 thermal conductivity gas chromatograph using helium as carrier gas. Use was made of a 15% Silicone SE 30 on Chromosorb W AW (⅜ in. × 10 ft) packed column. Column temperature is noted in the text.

Solvents and Materials. Benzene, THF, and DME for the cyclocoupling reaction were distilled from $LiAlH_4$. Dimethyl sulfoxide (Me_2SO), DMF, and furan were used after distillation from CaH_2. Freshly distilled morpholine was used for the synthesis of enamines. Preparations of $Fe_2(CO)_9$ from $Fe(CO)_5$,[18] Zn/Cu couple,[19] α,α′-dibromo ketones,[20] cyclohexanecarboxaldehyde,[21] 2,2-dimethylcyclopropanone in methylene chloride solution,[22] and enamines were performed according to the known procedures. Dibromo ketones were stored in a refrigerator and purified before use by passing through a short alumina column. All other organic substances (ketones employed for the synthesis of the dibromo ketones and enamines, solvents for extractive workup and chromatography, etc.) were used after simple distillation of commercially supplied ones. Reagent grade inorganic salts were used without further purification.

1-Morpholino-7,7,9,9-tetramethylbicyclo[4.3.0]nonan-8-one (3). A mixture of $Fe_2(CO)_9$ (437 mg, 1.20 mmol), 1-morpholinocyclohexene (**2**,[23] 510 mg, 3.06 mmol), and 2,4-dibromo-2,4-dimethylpentan-3-one (**1**, 272 mg, 1.00 mmol) in benzene (6.0 mL) was stirred at 60 °C with irradiation of a 200-W high-pressure Hg lamp through 10% aqueous $CuSO_4$ solution as filter (<350-nm cutoff). After 10 min the reaction mixture was cooled to room temperature and stirred with irradiation for an additional 12 h. The whole mixture was diluted with benzene (15 mL) and the organic layer was washed with saturated $NaHCO_3$ solution (3 mL × 2) and water (3 mL), and dried. Concentration of the benzene solution gave a yellow oil (565 mg), which was subjected to preparative TLC (1:10 ether–benzene), giving the ketone **3** (R_f 0.5, 243 mg, 87% yield) as crystals. An analytical specimen was collected by recrystallizations (pentane): mp 96–97 °C; IR 1732 cm^{-1} (C=O); NMR δ 1.02, 1.08, and 1.13 (three s, 1:1:2 ratio, 4 CH_3), 1.3–2.6 (m, 4 CH_2 and CH of carbocycles), 2.93 (m, 2 NCH_2), 3.53 (m, 2 OCH_2); mass spectrum *m/e* 279 (M^+), 208, 193, 167, 166. Anal. ($C_{17}H_{29}NO$) C, H, N.

The Cyclocoupling Reaction between Secondary Dibromo Ketones and Enamines. General Procedure. Unless otherwise stated, the cyclocoupling reaction was performed as follows. In a 30- or 50-mL two-necked flask equipped with a rubber septum, a magnetic stirrer,

and a three-way stopcock attached with a nitrogen- or argon-filled balloon was placed $Fe_2(CO)_9$, and the system was thoroughly deoxygenated by alternate pumping and filling inert gas (N_2 or argon) from the balloon. Into the system, benzene, an enamine, and a dibromo ketone were added separately by a syringe through the rubber septum. The resulting mixture was stirred with or without irradiation at the stated temperature until the reaction was complete. The reaction mixture was diluted with ethyl acetate (15–50 mL) and then treated with saturated $NaHCO_3$ solution (5–30 mL) and potassium nitrate solution (or brine). The organic layer was dried over anhydrous Na_2SO_4. The organic solution was concentrated under reduced pressure (50–90 mm), giving a crude material. The residue was subjected to preparative TLC or column chromatography on silica gel. In TLC separation, the silica gel layer of the cyclopentenone area absorbing the 254-nm light was collected and extracted with ethyl acetate. The progress of elution of column chromatography was monitored by analytical TLC and fractions including the desired product were combined and evaporated. When an undeaminated adduct was produced, the separated amine or, with more convenience, the whole reaction mixture was treated with 3% ethanolic NaOH solution (1–5 mL) at room temperature for 5–30 min. The cyclopentenone was obtained as a mixture of two diastereomers (except for **29** and **30**). The ratios of the two stereoisomers were determined by GLC and listed in Table III. The epimers could not be isolated in a pure form by the silica gel chromatography but were separated by preparative GLC. All spectral data were measured with a single epimer immediately after collection by preparative GLC. The IR and UV data are given in Table I. GLC retention times (t_R) as well as TLC R_f values of the cyclopentenones are summarized in Table III. Samples for elemental analysis were obtained by simple bulb-to-bulb distillation or recrystallizations of the chromatographed products. When the cyclopentenone was produced as a mixture of interconvertible diastereomers, the mixture was analyzed without separation.

2,4,4,5-Tetramethylcyclopent-2-enone (16). A mixture of 2,4-dibromopentan-3-one (**4**, 242 mg, 1.00 mmol), 1-morpholino-2-methylpropene (**8**,[23] 345 mg, 2.44 mmol), and $Fe_2(CO)_9$ (437 mg, 1.20 mmol) in benzene (3.0 mL) was stirred at 60 °C for 20 min and then at 25 °C for 12 h. The resulting mixture was worked up according to the general procedure to give an oil. Preparative TLC of the oil (1:20 ethyl acetate–hexane) gave **16** (29 mg) and 2,4,4,5-tetramethyl-3-morpholinocyclopentanone (R_f 0.05, 131 mg). The amino derivative was mixed with 3% ethanolic NaOH solution (4 mL) and allowed to stand at 25 °C for 5 min. The resulting mixture was diluted with water and extracted with ethyl acetate. The organic extract was washed with water, dried, and passed through a short column packed with silica gel. Concentration of the filtrate gave **16** (80 mg, 100% yield) as an oil. The combined yield of **16** was 109 mg (79%). NMR δ 0.97 and 1.20 (two s, $C(CH_3)_2$), 1.04 (d, J = 7.0 Hz, $CHCH_3$), 1.71 (d, J = 1.5 Hz, $=CCH_3$), 2.02 (q, J = 7.0 Hz, $CHCH_3$), 6.93 (q, J = 1.5 Hz, =CH); mass spectrum *m/e* 138 (M^+), 123, 110, 95. Anal. ($C_9H_{14}O$) C, H.

2,5-Dimethyl-3-phenylcyclopent-2-enone (17). A. On Large Scale.[24] To a suspension of $Fe_2(CO)_9$ (40.0 g, 110 mmol) in benzene (250 mL) were added **4** (24.4 g, 100 mmol) and α-morpholinostyrene (**9**,[25] 56.8 g, 300 mmol). The resulting mixture was maintained at 32 °C with stirring. After 20 h, E. Merck Kieselgel 60 (70–230 mesh) (230 g) and benzene (100 mL) were added and the resulting slurry was stirred at 32 °C for an additional 2.5 h. The whole mixture was poured onto a silica gel pad [the Merck gel, 150 g, 13 (diameter) × 2 cm (thickness)] with the aid of ether (200 mL). The pad was washed with ether (1 L). Organic layers were combined and concentrated, giving a brown liquid (ca. 40 g). The oil was distilled under reduced pressure by using a short-path distillation apparatus to give **17** (bp 100–105 °C at 0.02 mm, 15.6 g, 84% yield) as a pale yellow oil, which was crystallized by cooling with ice water. Recrystallizations from hexane afforded an analytical sample: mp 57–59 °C; NMR δ 1.22 (d, J = 7.0 Hz, $CHCH_3$), 1.91 (t, J = 2.0 Hz,[25] $=CCH_3$), 2.30 and 2.55 (two m, $CHCH_3$ and a CH_2 proton cis to CH_3), 3.14 (ddq, J = 18, 7.5, and 2.0 Hz,[25] a CH_2 proton trans to CH_3), 7.38 (m, C_6H_5); mass spectrum *m/e* 186 (M^+), 171, 158. Anal. ($C_{13}H_{14}O$) C, H.

B. On Usual Scale. A mixture of **4** (2.44 g, 10.0 mmol), **9** (3.78 g, 21.0 mmol), and $Fe_2(CO)_9$ (4.00 g, 11.0 mmol) in benzene (25 mL) was stirred at 30 °C for 20 h. The reaction mixture was worked up in a usual fashion to give an orange liquid (3.0 g). The oil was subjected to column chromatography (silica gel 150 g, 1:10 ethyl acetate–hexane) to yield **17** (1.68 g, 91% yield) as a semisolid, which was recrystallized from hexane, giving a pure sample, mp 57–59 °C.

Table III. Chromatographic Properties of Cyclopentenones

Cyclopentenone	Isomeric ratio,[a] trans/cis	TLC Eluent[b]	TLC R_f	GLC[c] Temp, °C	GLC t_R, min
16		A	0.25		
17		B	0.20		
trans-**18**	86:14	B	0.17	110	4.2
cis-**18**			0.17		5.6
trans-**19**	71:29	B	0.15	130	3.4
cis-**19**			0.10		5.2
trans-**20**	91:9	B	0.22	130	5.6
cis-**20**			0.18		7.4
trans-**21**	89:11	B	0.22	150	5.5
cis-**21**			0.18		7.2
trans-**22**	80:20	B	0.29	220	5.1
cis-**22**			0.25		5.9
23		C	0.26		
24		B	0.37		
25		D	0.41		
trans-**26**	70:30	B	0.27	130	4.1
cis-**26**			0.30		5.2
trans-**27**	64:36	A	0.18	140	8.3
cis-**27**			0.18		10.5
28		A	0.18		
trans-**29**	100:0	B	0.40	150	8.0
trans-**30**	100:0	C	0.28		

[a] Determined by GLC. [b] Performed using a column packed with 14% Silicone SE 30 on Chromosorb W AW (3 mm × 1 m). [c] The following solvent systems were used: A, 1:20 ethyl acetate–hexane; B, 1:10 ethyl acetate–hexane; C, 1:10 ether–hexane; D, 1:15 ethyl acetate–benzene.

3-Ethyl-2,4,5-trimethylcyclopent-2-enone (18). A mixture of $Fe_2(CO)_9$ (437 mg, 1.20 mmol), 3-morpholinopent-2-ene (**10**,[23] 465 mg, 3.00 mmol), and **4** (244 mg, 1.00 mmol) in benzene (2.5 mL) was stirred at 45 °C for 18 h. The mixture was usually worked up to give oily residue (217 mg). The chromatography (1:10 ethyl acetate–hexane) gave **18** (111 mg, 73% yield) as an oil. Anal. ($C_{10}H_{16}O$) C, H. The stereoisomeric mixture was separated by preparative GLC (150 °C), affording *trans*- and *cis*-**18** in a pure state.

trans-**18:** NMR δ 1.10 (t, J = 8.0 Hz, CH_2CH_3), 1.11 (d, J = 7.0 Hz, $COCHCH_3$), 1.18 (d, J = 7.0 Hz, $=CCHCH_3$), 1.63 (d, J = 2.0 Hz, $=CCH_3$), 1.77 (dq, J = 2.5 and 7.0 Hz, $COCHCH_3$), 2.1–2.6 (m, CH_2 and $=CCHCH_3$); mass spectrum *m/e* 152 (M^+), 137, 124, 123, 109, 95.

cis-**18:** NMR δ 1.03 (d, J = 7.5 Hz, 2 $CHCH_3$), 1.12 (t, J = 8.0 Hz, CH_2CH_3), 1.64 (t, J = 1.0 Hz, $=CCH_3$), 2.1–2.7 (m, CH_2 and $COCHCH_3$), 2.86 (quintet, J = 7.5 Hz, $=CCHCH_3$); mass spectrum *m/e* 152 (M^+), 137, 124, 123, 109, 95.

2,4-Dimethylbicyclo[3.3.0]oct-1-en-3-one (19). A mixture of 1-morpholinocyclopentene (**11**,[23] 510 mg, 3.33 mmol), $Fe_2(CO)_9$ (437 mg, 1.20 mmol), and **4** (242 mg, 1.00 mmol) in benzene (3.0 mL) was stirred at 25 °C for 12 h. The resulting mixture was worked up in a usual manner to produce a yellow oil, which was subjected to preparative TLC (1:10 ethyl acetate–hexane). The cyclopentenone **19** (111 mg, 74% yield) was collected. Anal. ($C_{10}H_{14}O$) C, H. The two epimers were isolated as a single substance by preparative GLC (180 °C).

trans-**19:** NMR δ 0.9–1.4 (m, one of CH_2 protons), 1.17 (d, J = 7.0 Hz, $CHCH_3$), 1.65 (four lines, J = 1.5 Hz, $=CCH_3$), 1.8–2.6 (m, 2 CH_2, one of CH_2 protons, and 2 CH); mass spectrum *m/e* 150 (M^+), 135, 122, 107, 79.

cis-**19:** NMR δ 0.68 (d, J = 7.0 Hz, $CHCH_3$), 0.8–1.1 (m, one of CH_2 protons), 1.36 (four lines, J = 1.5 Hz, $=CCH_3$), 1.4–2.0 (m, CH_2, one of CH_2 protons, and $CHCH_3$), 2.17 (t, J = 7.0 Hz, $=CCH_2$), 2.3–2.8 (m, =CCH); mass spectrum *m/e* 150 (M^+), 135, 122.

7,9-Dimethylbicyclo[4.3.0]non-1(9)-en-8-one (20). A mixture of $Fe_2(CO)_9$ (4.37 g, 12.0 mmol), **2** (5.10 g, 30.5 mmol), and **4** (1.95 g, g, 7.99 mmol) in benzene (25 mL) was stirred at 25 °C for 24 h and worked up as usual. The residual oil was passed through a short alumina column for removal of the resulting brown precipitates and the

column was washed with ethyl acetate. Evaporation of the washing followed by column chromatography (silica gel, 80 g, 1:10 ethyl acetate-hexane) gave rise to **20** (1.32 g, 100% yield) as an oil. Anal. ($C_{11}H_{16}O$) C, H. Preparative GLC (200 °C) gave analytical samples of *trans*- and *cis*-**20.**

trans-**20:** NMR δ 0.9-2.4 (m, 4 CH_2 and $CHCH_3$), 1.10 (d, J = 8.0 Hz, $CHCH_3$), 1.63 (d, J = 1.0 Hz, $=CCH_3$), 2.84 (m, $=CCH$); mass spectrum *m/e* 164 (M^+), 149, 136, 107.

cis-**20:** NMR δ 1.00 (d, J = 7.0 Hz, $CHCH_3$), 1.0-3.0 (m, 4 CH_2 and 2 CH), 1.62 (t, J = 1.0 Hz, $=CCH_3$); mass spectrum *m/e* 164 (M^+), 149, 136, 107.

Reaction of **4** and **2** in the presence of Zn-Cu couple also afforded **20.** A mixture of Zn-Cu couple (78 mg, 1.20 mg-atoms), **4** (244 mg, 1.00 mmol), and **2** (669 mg, 4.00 mmol) in DME (5.0 mL) was stirred at −5 °C for 30 min and then at 25 °C for 16 h. The reaction mixture was diluted with ether, poured into saturated $NaHCO_3$ solution, and shaken. The organic layer was washed with brine, dried, and concentrated, giving an oil (480 mg). This was treated with 3% ethanolic NaOH solution (3 mL) at 25 °C for 1 h and diluted with water and ether. The separated organic layer was dried and evaporated to leave a yellow oil, which was distilled using a bulb-to-bulb system [bp 110-150 °C (bath temperature), 0.3 mm]. The distillate (106 mg) was subjected to preparative TLC (1:10 ethyl acetate-hexane), producing the ketone **20** (66 mg, 39% yield).

Reaction of **4** and **2** with NaI did not afford **20.** A solution of NaI (750 mg, 5.00 mmol), **4** (141 mg, 0.50 mmol), and **2** (250 mg, 1.50 mmol) in acetone (2.5 mL) was stirred at 25 °C for 8 h. After evaporation, to the remaining material was added ethyl acetate. The organic layer was washed with $Na_2S_2O_3$ solution, water, and KNO_3 solution, and dried. Concentration followed by preparative TLC (1:4 ethyl acetate-benzene) afforded recovered **4** (R_f 0.8, 24 mg, 20%) and 2-morpholinopentan-3-one [R_f 0.17, 25 mg, 29% yield: IR ($CHCl_3$) 1712 cm^{-1} (C=O); NMR ($CDCl_3$) δ 1.01 (t, J = 7.5 Hz, CH_2CH_3), 1.11 (d, J = 7.0 Hz, $CHCH_3$), 2.2-2.8 (m, 2 NCH_2 and CH_2CH_3), 3.12 (q, J = 7.0 Hz, $CHCH_3$), 3.71 (m, 2 OCH_2); mass spectrum *m/e* 171 (M^+)].

8,10-Dimethylbicyclo[5.3.0]dec-1(10)-en-9-one (21). A mixture of $Fe_2(CO)_9$ (437 mg, 1.20 mmol), 1-morpholinocycloheptene (**12**,[23] 510 mg, 2.81 mmol), and **4** (244 mg, 1.00 mmol) in benzene (2.5 mL) was stirred at 25 °C for 14 h. Usual workup left a brown oil. Preparative TLC (1:10 ethyl acetate-hexane) afforded **21** (180 mg, 100% yield). Anal. ($C_{12}H_{18}O$) C, H. Preparative GLC separation (200 °C) produced the stereoisomers in a pure form.

trans-**21:** NMR δ 1.12 (d, J = 7.0 Hz, $CHCH_3$), 1.3-2.1 (m, 4 CH_2 and $CHCH_3$), 1.61 (fine splitting m, $=CCH_3$), 2.2-2.7 (m, $=CCH_2$ and $=CCH$); mass spectrum *m/e* 178 (M^+), 163, 150, 135.

cis-**21:** NMR δ 1.01 (d, J = 7.5 Hz, $CHCH_3$), 1.0-2.1 (m, 4 CH_2), 1.61 (fine splitting m, $=CCH_3$), 2.40 (quintet, J = 7.5 Hz, $CHCH_3$), 2.5-2.9 (m, $=CCH_2$ and $=CCH$); mass spectrum *m/e* 178 (M^+), 163, 150, 135.

13,15-Dimethylbicyclo[10.3.0]pentadec-1(15)-en-14-one (22). A mixture of $Fe_2(CO)_9$ (437 mg, 1.20 mmol), 1-morpholinocyclododecene (**13**,[23] 505 mg, 2.00 mmol), and **4** (244 mg, 1.00 mmol) in benzene (2.5 mL) was stirred at 45 °C for 19 h. The mixture was worked up in a usual manner to afford a brown oil. Its preparative TLC (1:10 ethyl acetate-hexane, two developments) gave **22** (223 mg, 90% yield) as a colorless oil. Anal. ($C_{17}H_{28}O$) C, H. Pure *trans*- and *cis*-**22** were collected by preparative GLC (260 °C).

trans-**22:** NMR δ 1.0-2.0 (m, 9 CH_2), 1.11 (d, J = 7.0 Hz, $CHCH_3$), 1.63 (d, J = 2.0 Hz, $=CCH_3$), 2.90 (dq, J = 2.0 and 7.0 Hz, $CHCH_3$), 2.36 (m, $=CCH_2$ and $=CCH$); mass spectrum *m/e* 248 (M^+), 233, 220, 191, 135, 124.

cis-**22:** NMR δ 1.08 (d, J = 7.0 Hz, $CHCH_3$), 1.1-1.8 (m, 9 CH_2), 1.65 (d, J = 2.0 Hz, $=CCH_3$), 2.2-2.5 (m, $=CCH_2$ and $CHCH_3$), 2.85 (m, $=CCH$); mass spectrum *m/e* 248 (M^+), 233, 220, 191, 135, 124.

1,3-Dimethylspiro[4.5]dec-3-en-2-one (23). A mixture of **4** (244 mg, 1.00 mmol), 4-(cyclohexylidenemethyl)morpholine (**14**,[23] 544 mg, 3.00 mmol), and $Fe_2(CO)_9$ (437 mg, 1.20 mmol) in benzene (3.0 mL) was stirred at 42 °C for 18 h. The reaction mixture was subjected to usual extractive workup, affording an oil (405 mg). The material was dissolved in benzene (5 mL) and treated with E. Merck Kieselgel 60 (70-230 mesh) (800 mg) at 25 °C for 1 h with stirring. After removal of silica gel by filtration the filtrate was evaporated to give an oil (344 mg), which was subjected to preparative TLC (1:10 ethyl acetate-hexane), yielding **23** (115 mg) and an oil containing 1,3-dimethyl-4-morpholinospiro[4.5]decan-2-one (R_f 0.15, 61 mg). This oil was treated with 3% ethanolic NaOH solution (4 mL) at 25 °C for 1 h. The reaction was quenched by the addition of a saturated NH_4Cl solution and the aqueous mixture was extracted with ethyl acetate. The organic layer was dried and concentrated, leaving oily material. Preparative TLC (1:10 ethyl acetate-hexane) gave rise to **23** (13 mg). Total yield of **23** was 128 mg (71%). NMR δ 1.03 (d, J = 7.5 Hz, $CHCH_3$), 1.73 (d, J = 1.5 Hz, $=CH_3$), 1.97 (q, J = 7.5 Hz, $CHCH_3$), 1.0-2.0 (envelope, 5 CH_2), 7.36 (q, J = 1.5 Hz, $=CH$); mass spectrum *m/e* 178 (M^+), 163, 150, 135. Anal. ($C_{12}H_{18}O$) C, H.

Cyclododecanecarboxaldehyde. To a stirred suspension of methoxymethyltriphenylphosphonium chloride (26.5 g, 77.3 mmol)[27] in DME (100 mL) was added dropwise at −30 °C a solution of dimsyl sodium in Me_2SO freshly prepared from NaH (1.60 g, 66.7 mmol) and Me_2SO (30 mL).[28] After keeping the resulting red mixture at −40 to −30 °C for 10 min, a solution of cyclododecanone (11.5 g, 63.2 mmol) in DME (30 mL) was added slowly with efficient stirring. After the addition was complete, the reaction mixture was stirred at −20 to −10 °C for 1 h and at 25 °C for 3 h and then quenched with cold water. The resulting precipitates were removed by filtration and the filtrate was extracted with 1:1 ethyl acetate-hexane (100 mL). The organic extract was dried and evaporated to give a yellow oil (20 g). The oil was dissolved in a mixture of THF (55 mL), water (85 mL), and 70% $HClO_4$ (0.7 mL), and the solution was heated at reflux for 2 h. The mixture was quenched by the addition of saturated $NaHCO_3$ solution (5 mL) and concentrated in vacuo until the volume was reduced to about 20 mL. The aqueous residue was extracted with benzene and the organic layer was dried. Removal of the solvent left oily material (20 g). Column chromatography of the oil (silica gel, 200 g, 1:20 ethyl acetate-hexane) afforded cyclododecanecarboxaldehyde (R_f 0.42, 5.80 g, 52% yield) as an oil: IR 2825 and 2690 (CHO), 1725 cm^{-1} (C=O); NMR δ 1.40 (envelope, 11 CH_2), 2.36 (m, $CHCHO$), 9.72 (d, J = 1.5 Hz, CHO); mass spectrum *m/e* 196 (M^+).

This aldehyde is highly air sensitive and readily oxidized on standing under atmosphere, yielding cyclododecanecarboxylic acid, mp 97-98 °C. Immediate use is recommended.

4-(Cyclododecylidenemethyl)morpholine (15). A mixture of freshly prepared cyclododecanecarboxaldehyde (3.60 g, 17.5 mmol), morpholine (3.20 g, 35.9 mmol), and a catalytic amount of *p*-toluenesulfonic acid in benzene (16 mL) was heated under reflux for 20 h by use of a Dean-Stark water separation system. The reaction mixture was concentrated and distilled with a short-path distillation apparatus. The enamine **15** was collected as a colorless oil (bp 110-117 °C at 0.15 mm, 4.00 g, ca. 98% pure, 86% yield): NMR (benzene) (benzene signal at δ 7.37 as internal standard) δ 1.4-1.8 (envelope, 9 CH_2 of carbocycle), 1.8-2.7 (m, 2 $=CCH_2$), 2.62 (t-like m, J = 4.5 Hz, 2 NCH_2), 3.80 (t-like m, J = 4.5 Hz, 2 OCH_2), 5.50 (s, $=CH$); mass spectrum *m/e* 265 (M^+).

1,3-Dimethylspiro[4.11]hexadec-3-en-2-one (24). A mixture of $Fe_2(CO)_9$ (437 mg, 1.20 mmol), **4** (244 mg, 1.00 mmol), and **15** (400 mg, 1.50 mmol) in benzene (2.5 mL) was stirred at 25 °C for 12 h and worked up. The resulting pale yellow oil (300 mg) was subjected to preparative TLC (1:10 ethyl acetate-hexane), yielding **24** (164 mg, 65% yield) as colorless crystals. An analytical sample, mp 84-86 °C, was collected by recrystallizations from cold petroleum ether (−20 °C): NMR δ 1.05 (d, J = 7.0 Hz, $CHCH_3$), 1.69 (d, J = 1.2 Hz, $=CCH_3$), 1.2-1.8 (envelope, 11 CH_2), 1.8-2.3 (m, $CHCH_3$), 6.95 (q, J = 1.2 Hz, $=CH$); mass spectrum *m/e* 262 (M^+), 247, 234, 219, 206. Anal. ($C_{18}H_{30}O$) C, H.

2,5-Diethyl-3-phenylcyclopent-2-enone (25). A mixture of 3,5-dibromoheptan-4-one (**5**, 272 mg, 1.00 mmol), **9** (535 mg, 2.70 mmol), and $Fe_2(CO)_9$ (437 mg, 1.20 mmol) in benzene (2.5 mL) was stirred at 25 °C for 14 h. Usual workup yielded an orange oil (250 mg). Preparative TLC (1:15 ethyl acetate-benzene) afforded **25** (130 mg, 64% yield) as an oil: NMR δ 0.95 and 1.08 (two t, J = 7.5 Hz, 2 CH_2CH_3), 1.2-2.0 (m, $CHCH_2CH_3$), 2.1-2.7 (m, $=CCH_2CH_3$, COCH, and a CH_2 proton cis to C_2H_5), 3.40 (m, a CH_2 proton trans to C_2H_5), 7.31 (narrow m, C_6H_5); mass spectrum *m/e* 214 (M^+), 213, 200, 187, 186. Anal. ($C_{15}H_{18}O$) C, H.

4-Methyl-2,3,5-triethylcyclopent-2-enone (26). A mixture of **5** (272 mg, 1.00 mol), **10** (465 mg, 3.00 mmol), and $Fe_2(CO)_9$ (437 mg, 1.20 mmol) in benzene (2.5 mL) was maintained at 46 °C with stirring for 16 h. Usual workup produced **26** (126 mg, 70% yield). Anal. ($C_{12}H_{20}O$) C, H. Analytical *trans*- and *cis*-**26** were collected by preparative GLC (180 °C).

trans-**26:** NMR δ 0.96 (t, J = 7.0 Hz, $CHCH_2CH_3$), 1.03 and 1.12 (two t, J = 8.0 and 7.5 Hz, respectively, 2 $=CCH_2CH_3$), 1.17 (d, J = 7.0 Hz, $CHCH_3$), 1.2–1.8 (m, $CHCH_2CH_3$ and COCH), 2.11 (q, J = 8.0 Hz, $=CCH_2CH_3$), 2.2–2.6 (m, CH_2CH_3 and $=CCHCH_3$); mass spectrum *m/e* 180 (M^+), 165, 152, 137, 123.

cis-**26:** NMR δ 0.95, 1.05, and 1.12 (three t, J = 8.0, 7.0, and 8.0 Hz, respectively, 3 CH_2CH_3), 1.08 (d, J = 7.0 Hz, $CHCH_3$), 1.0–1.5 and 1.70 (two m, $CHCH_2CH_3$), 1.9–2.7 (m, 2 $=CCH_2$ and COCH), 2.90 (five lines, J = 7.0 Hz, $=CCHCH_3$); mass spectrum *m/e* 180 (M^+), 165, 152, 137, 123.

7,9-Diethylbicyclo[4.3.0]non-1(9)-en-8-one (27). A mixture of $Fe_2(CO)_9$ (437 mg, 1.20 mmol), **2** (510 mg, 3.05 mmol), and **5** (272 mg, 1.00 mmol) in benzene (3.0 mL) was stirred at 25 °C under irradiation of a 200-W high-pressure Hg arc with 10% aqueous $CuSO_4$ solution as <350-nm cutoff filter. After 12 h, the mixture was worked up to give an oil (296 mg). Subsequent preparative TLC (1:10 ethyl acetate–hexane) afforded **27** (170 mg, 89% yield) as an oil. Anal. ($C_{13}H_{20}O$) C, H. Preparative GLC (200 °C) produced pure *trans*- and *cis*-**27.**

trans-**27:** NMR δ 0.95 (t, J = 7.0 Hz, 2 CH_3), 1.0–2.3 (m, 6 CH_2 and COCH), 2.84 (m, $=CCH$); mass spectrum *m/e* 192 (M^+), 177, 164, 149, 135.

cis-**27:** NMR δ 0.95 and 1.05 (two t, J = 7.0 Hz, 2 CH_3), 1.1–2.3 (m, 6 CH_2), 2.63 (dt, J = 7.0 and 6.0 Hz, COCH), 2.84 (m, $=CCH$); mass spectrum *m/e* 192 (M^+), 177, 164, 149, 135.

2,5-Diisopropyl-3-phenylcyclopent-2-enone (28). A mixture of 3,5-dibromo-2,6-dimethylheptan-4-one (**6,** 510 mg, 1.70 mmol), **9** (963 mg, 5.09 mmol), and $Fe_2(CO)_9$ (874 mg, 2.40 mmol) in benzene (5.0 mL) was heated at 30 °C for 15 h and worked up. The resulting viscous oil was treated with 3% ethanolic NaOH solution at 25 °C for 5 min and then diluted with ethyl acetate and water. The organic layer was washed with water and dried. Removal of the organic solvents followed by preparative TLC (1:20 ethyl acetate–hexane) afforded **28** (293 mg, 72% yield) as crystals. An analytical specimen, mp 38–40 °C (needles), was obtained by recrystallizations from hexane: NMR δ 0.81 and 1.00 (two d, J = 6.5 Hz, $CHCH(CH_3)_2$), 1.19 and 1.21 (two d, J = 7.0 Hz, $=CCH(CH_3)_2$), 1.8–2.5 (m, $CHCH(CH_3)_2$), 2.5–3.1 (m, $=CCH_2$ and $CCH(CH_3)_2$), 7.32 (narrow m, C_6H_5); mass spectrum *m/e* 242 (M^+), 241, 228, 199, 185. Anal. ($C_{17}H_{22}O$) C, H.

7,9-Diisopropylbicyclo[4.3.0]non-1(9)-en-8-one (29). A mixture of $Fe_2(CO)_9$ (874 mg, 2.40 mmol), **2** (918 mg, 5.48 mmol), and **6** (510 mg, 1.70 mmol) in benzene (5.0 mL) was heated at 32 °C with stirring for 12 h, quenched, and worked up, giving oily material. The oil was treated with 3% ethanolic NaOH solution at 25 °C for 10 min and quenched with water. The aqueous mixture was extracted with ethyl acetate (10 mL × 3) and the organic extracts were dried. Removal of the solvents afforded an oil, which was subjected to preparative TLC (1:10 ethyl acetate–hexane) to give *trans*-**29** (274 mg, 73% yield, a single product) as colorless crystals. Recrystallizations from hexane produced an analytical sample as needles: mp 47–47.5 °C; NMR δ 0.74, 0.97, and 1.13 (three d, 1:1:2 ratio, J = 7.0 Hz, 4 CH_3), 0.9–2.3 (m, 4 CH_2, COCH, and $CH(CH_3)_2$), 2.5–3.0 (m, 2 $=CCH$); mass spectrum *m/e* 220 (M^+), 205, 178, 163. Anal. ($C_{15}H_{24}O$) C, H.

2,4-Diphenylbicyclo[3.3.0]oct-1-en-3-one (30). A mixture of 1,3-dibromo-1,3-diphenylpropan-2-one (**7,** 368 mg, 1.00 mmol), **11** (510 mg, 3.33 mmol), and $Fe_2(CO)_9$ (437 mg, 1.20 mmol) in benzene (3.0 mL) was stirred at 30 °C for 22 h. The resulting mixture was subjected to the usual workup to afford a viscous, brown oil (380 mg). The residue was mixed with 3% ethanolic NaOH solution (1.0 mL) and stirred at 25 °C for 30 min. The mixture was diluted with water (10 mL) and extracted with ethyl acetate (10 mL × 2). The organic extracts were combined, dried, and concentrated, giving a brown oil (300 mg). Preparative TLC of the oil (1:3 ethyl acetate–hexane) produced *trans*-**30** (182 mg, 66% yield, a single isomer) as yellow crystals. Recrystallizations from hexane yielded an analytical sample as colorless needles, mp 115–116 °C (lit.[9] 117–118 °C). Its spectral data (IR, NMR, UV, and mass) were identical with the reported ones.[9]

Interconversion between *cis*- and *trans*-20. Pure *cis*-**20** (1.0 mg, 6.1 × 10^{-4} mmol) was mixed with 3% ethanolic NaOH solution (0.5 mL) and allowed to stand at 25 °C for 20 h. The whole mixture was quenched by the addition of water (1 mL) and then shaken with ethyl acetate (1 mL) vigorously. GLC analysis of the organic layer indicated the formation of a mixture of *cis*- and *trans*-**20** in a 1:9 ratio. The same treatment of *trans*-**20** also afforded a stereoisomeric mixture of the cyclopentenones (cis/trans = 1:9).

1,3-Dimethylazulene (33). A mixture of **21** (178 mg, 1.00 mmol) and $NaBH_4$ (180 mg, 12.0 mmol) in ethanol (6 mL) was stirred at 25 °C for 14 h. Evaporation of the mixture left a slurry, which was diluted with ethyl acetate (2 mL) and acidified by the addition of cold 1 N HCl. The resulting heterogeneous mixture was stirred at 25 °C for 30 min. The organic layer was washed with saturated $NaHCO_3$ solution (10 mL) and KNO_3 solution and dried. Removal of the solvent gave an oil (210 mg). The oil was mixed with sulfur (100 mg, 3.00 mg-atoms) in a sealed tube under N_2 and heated at 290–300 °C for 12 min. During the period, vigorous gas evolution was observed. After cooling, the black mixture was subjected directly to column chromatography (silica gel, 4.0 g, hexane), giving the azulene **33** (R_f 0.5, 43 mg, 28% yield) as a blue semisolid. An analytical sample, mp 51–53 °C (lit.[29] 54 °C), was obtained by recrystallizations from ethanol (−30 °C). Its UV-visible spectral data were identical with the reported ones.[29,30]

Reaction of Dibromo Ketone 4 and Enamine 2 in the Absence of Reducing Agent. A solution of **4** (73 mg, 0.30 mmol) and **2** (50 mg, 0.30 mmol) in benzene (0.3 mL) was allowed to stand at 25 °C for 24 h. The NMR spectrum of the solution was a superposition of those of **4** and **2** in benzene. The two components did not react in furan either.

Reaction of 4 and 2 with $Fe_2(CO)_9$ in Furan. A mixture of $Fe_2(CO)_9$ (437 mg, 1.20 mmol), **4** (244 mg, 1.00 mmol), and **2** (520 mg, 3.06 mmol) in furan (2.50 mL, 2.36 g, 34.6 mmol) was stirred at 25 °C for 24 h. After dilution with ethyl acetate (5 mL), the reaction mixture was stirred with E. Merck Kieselgel 60 (70–230 mesh) (2.0 g) at 25 °C for 2.5 h. Silica gel was removed by filtration and washed with ethyl acetate (20 mL). The filtrate was concentrated to give a yellow oil (340 mg). GLC analysis (115 °C using tridecane as an internal standard) of the oil showed the formation of a mixture of **20** (two isomers, t_R 10.2 and 14.5 min, respectively, 4% combined yield) and 2,4-dimethyl-8-oxabicyclo[3.2.1]oct-6-en-3-one (**37**)[15,31] [a 2:1 mixture of cis(α,α) and trans diastereomers (NMR), t_R 4.2 min, 35% yield]. The reaction of **4** (244 mg, 1.00 mmol) and **2** (520 mg, 3.06 mmol) in the presence of $Fe_2(CO)_9$ (437 mg, 1.20 mmol) in furan (2.36 g, 34.6 mmol) at 40 °C for 24 h, followed by the same workup, gave a mixture of **20** and **37** in 10 and 90% yields, respectively (GLC).

Reaction of 2,2-Dimethylcyclopropanone and 2. To chilled (−30 °C) **2** (260 mg, 1.53 mmol) was added a 1 M solution of 2,2-dimethylcyclopropanone in CH_2Cl_2 (0.50 mL), and the homogeneous mixture was allowed to stand at 25 °C for 20 h under N_2. Concentration of the reaction mixture afforded a viscous oil containing some solids. The IR spectrum showed a small carbonyl absorption at 1715 cm^{-1}, not arising from cyclopentanones. Neither TLC nor GLC showed any signs of production of the desired cycloadducts.

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Synthesis, Properties, and Reactions of Dispiro[2.2.2.2]deca-4,9-diene

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Abstract: Dispiro[2.2.2.2]deca-4,9-diene (**1**) was prepared in five steps from diethyl succinate. This particular cyclopropylethylene exhibits a relatively large bathochromic shift of the absorption maximum (222 nm) in UV and a marked lowering of the ionization potential (7.23 eV) compared to *cis*-1,2-dicyclopropylethylene (203.5 nm in UV and IP 7.70 eV). The chemical shift of the olefinic protons, however, does not suggest the existence of cyclic conjugation in **1**. The spiro olefin **1** underwent interesting cycloadditions with a variety of unsaturated compounds. (1) It reacts with conjugated dienes at 160 °C to give [8]paracycloph-4-enes, **13** and **14**. The two cyclopropane rings are cleaved and the central cyclohexadiene ring is aromatized. (2) It reacts with dimethyl maleate or dimethyl acetylenedicarboxylate at 160 °C to afford dispiro[2.2.4.2]dodecane derivatives, **22** and **23**. One of the cyclopropanes is cleaved, to which the reacting olefin cycloadds. (3) It reacts with tetracyanoquinodimethane in *o*-dichlorobenzene to produce a [3.3]paracyclophane derivative, **30**. The first two cycloadditions are proved to proceed via biradical intermediates, while the last reaction involves a zwitterionic intermediate which can be trapped by polar multiple bonds. Conformational equilibria of some cycloadducts are also discussed.

It is known that conjugative interaction between a cyclopropane ring and a double bond is maximized when a bisected conformation is attained.[1] Dispiro[2.2.2.2]deca-4,9-diene (**1**) where the double bonds and the cyclopropane rings are aligned alternately around the six-membered ring in the bisected conformation is, therefore, of considerable interest for a number of reasons including (1) the possibility of cyclic con-

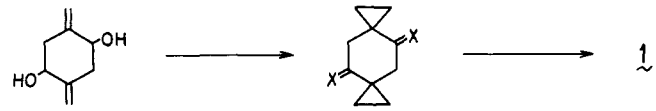
1

jugation through the cyclopropane rings geminally substituted by the double bonds, (2) the π-base character due to the electron-donating property of a cyclopropane ring, and (3) the expected formation of the species, via the cleavage of the cyclopropane ring, whose spiro[2.5]octane moiety possesses the same structure as an intermediate (or a species in the transition state) postulated for 1,2-aryl migration.[2]

Herein we describe the preparation of **1**, its properties, and some interesting reactions of **1** which proceed via homolysis as well as heterolysis of the cyclopropane ring and provide a convenient route to a variety of paracyclophane derivatives.

Results and Discussion

Synthesis and Properties of Dispiro[2.2.2.2]deca-4,9-diene. 2,5-Dimethylene-1,4-cyclohexanediol (**2**), prepared from diethyl succinate following the procedure of Murphy,[3] was cyclopropanated with methylene iodide and zinc–copper couple[4] to give the dispiro diol (**3**), which was subsequently oxidized with the Jones reagent to the diketone (**4**). Treatment of the bistosylhydrazone of **4** with *n*-butyllithium[5] afforded dispiro[2.2.2.2]deca-4,9-diene (**1**) in a 64% yield. The dispiro compound, **1**, could be obtained as volatile, colorless plates melting at 121–122 °C. Proof of the structure of **1** was pro-



2 **3**, X = H, OH; **5**, X = H, OC(S)SCH$_3$
4, X = O ; **6**, X = H, SC(O)SCH$_3$

vided by its elemental analysis and spectral properties. Synthesis of **1** was also attempted by the pyrolysis of the bisxanthate of **3**. When the temperature of the heating bath was slowly raised, the xanthate (**5**) isomerized almost quantitatively

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