Registry No.—**3a,** 10330-37-7; **3b,** 10330-36-6; **3c,** 53927-14-3; **4a,** 29773-67-9; **4b,** 2862-90-0; **4c,** 53927-15-4; **7,** 42161-96-6; **8a,** 53927-16-5; **8b,** 53927-17-6; **8c,** 53927-18-7; **9a,** 53927-19-8; **9b,** 53927-20-1; **9c,** 53927-21-2; **10b,** 5689-04-3; **11b,** 16484-17-6; **12b,** 2826-65-5; **13b,** 18955-93-6; **13b** semicarbazone, 53927-22-3; **14a,** 53927-23-4; **14b,** 53927-24-5; **15a,** 28436-04-6; **15b,** 28436-03-5; **16a,** 53927-25-6; **16b,** 53927-26-7; **18,** 53927-27-8; **19,** 53927-28-9; cyclopropyl methyl ketone, 765-43-5; ethyl bicyclo[4.1.0]heptan-7-yl ketone, 53927-29-0; 1-(1-methylcylclohexen-2-yl)propan-2-one, 53927-30-3; chlorotrimethylsilane, 75-77-4; 1-indanone, 83-33-0; 1-hexahydroindanol, 53927-31-4.

References and Notes

(1) Financial support of this research by the Robert A. Welch Foundation is gratefully acknowledged.
(2) R. A. Ellison, *Synthesis,* 397 (1973); P. T. Lansbury, *Acc. Chem. Res.,* **5,** 311 (1972); R. F. Romanet and R. H. Schlessinger, *J. Am. Chem. Soc.,* **96,** 3701 (1974); S. Danishefsky, J. Dynak, E. Hatch, and M. Yamamato, ibid., **96,** 1256 (1974); W. S. Johnson, M. B. Gravestock, R. J. Parry, R. F. Meyers, T. A. Bryson, and D. H. Miles, ibid., **93,** 4330 (1971); J. E. McMurry and T. E. Glass, *Tetrahedron Lett.,* 2575 (1971); E. Wenkert, R. A. Muller, E. J. Reardon, Jr., S. S. Suthe, D. J. Scharf, and G. Tori, *J. Am. Chem. Soc.,* **92,** 7428 (1970); A. I. Meyers and N. Nazarenko, *J. Org. Chem.,* **38,** 175 (1973).
(3) P. L. Fuchs, *J. Am. Chem. Soc.,* **96,** 1607 (1974); J. P. Marino and W. B. Mesbergen, ibid., **96,** 4050 (1974); R. Noyori, K. Yooyama, and Y. Hayakawa, ibid., **95,** 2722 (1973); R. Noyori, K. Yokoyama, S. Makino, and Y. Hayakawa, ibid., **94,** 1772 (1972).
(4) (a) E. J. Corey and S. W. Walinsky, *J. Am. Chem. Soc.,* **94,** 8932 (1972); (b) T. Hiyama, M. Tsakanaka, and H. Nozaki, ibid., **96,** 3713 (1974); (c) H. C. Brown, *Acc. Chem. Res.,* **2,** 65 (1969).
(5) G. Buchi and B. Egger, *J. Org. Chem.,* **36,** 2021 (1971); G. Buchi, U. Hochstrasser, and W. Pawlak, ibid., **38,** 4348 (1973).
(6) B. M. Trost and M. J. Bogdanowicz, *J. Am. Chem. Soc.,* **95,** 5311 (1973); B. M. Trost, *Acc. Chem. Res.,* **7,** 85 (1974).
(7) C. D. Gutsche and D. Redmore, "Advances in Alicyclic Chemistry", Supplement 1, Academic Press, New York, N.Y., 1968, Chapter 9; for a comprehensive bibliography, see ref 18 in Trost and Bogdanowicz.[6]
(8) H. O. House, L. J. Czuba, M. Gall, and H. D. Olmstead, *J. Org. Chem.,* **34,** 2324 (1969).
(9) Enolization of cyclopropyl alkyl ketones *away* from the three-membered ring is well established: H. W. Amburn, K. C. Kauffman, and H. Schecter, *J. Am. Chem. Soc.,* **91,** 530 (1969).
(10) M. K. Jorgenson, *Org. React.,* **18,** 1 (1970).
(11) E. J. Corey and M. Chaykousky, *J. Am. Chem. Soc.,* **87,** 1353 (1965).
(12) Similar stereoselectivity has been observed in the alkylation of trans γ-butyrolactones: P. A. Grieco and M. Miyashita, *J. Org. Chem.,* **39,** 120 (1974).
(13) R. M. Roberts, R. G. Landolt, R. N. Greene, and E. W. Heyer, *J. Am. Chem. Soc.,* **89,** 1404 (1967); D. L. Garin, *J. Org. Chem.,* **35,** 2830 (1970).
(14) R. G. Bergman and W. L. Carter, *J. Am. Chem. Soc.,* **91,** 7411 (1969).
(15) P. H. Mazzocchi and H. J. Tamburin, *J. Am. Chem. Soc.,* **92,** 7220 (1970), and references cited therein.
(16) R. B. Woodward and R. Hoffmann, "The Conservation of Orbital Symmetry", Verlag Chemie, Weinheim/Bergstr., Germany, 1970, pp 121–122.
(17) P. D. Bartlett, L. K. Montgomer, and B. Seidel, *J. Am. Chem. Soc.,* **86,** 616 (1964); C. Walling and W. Thaler, ibid., **83,** 3877 (1961); R. Sustmann and H. Trill, ibid., **96,** 4343 (1974).
(18) A. D. Ketley, A. J. Berlin, and L. P. Fisher, *J. Org. Chem.,* **31,** 2648 (1966).
(19) Experimental data to support a diradical mechanism for the rearrangement of more hindered cisoid vinylcyclopropane substrates have been advanced.[15]
(20) K. E. Harding, *Bioorg. Chem.,* **2,** 248 (1973).
(21) Cf. ref 6 and 8 and G. Stork and P. F. Hudrlik, *J. Am. Chem. Soc.,* **90,** 4462, 4464 (1968); H. O. House, M. Gall, and H. D. Olmstead, *J. Org. Chem.,* **36,** 2361 (1971).
(22) Commercially available from Aldrich Chemical Co.
(23) R. T. LaLonde and M. A. Tobias, *J. Am. Chem. Soc.,* **86,** 4068 (1964).
(24) J. Novak, J. Ratusky, V. Sneberg, and F. Šorm, *Chem. Listy,* **51,** 479 (1951); *Chem. Abstr.,* **51,** 10508e (1957).
(25) J. A. Berson and G. S. Hand, *J. Am. Chem. Soc.,* **86,** 1978 (1964).
(26) W. Kirmse and K. H. Pook, *Chem. Ber.,* **98,** 4022 (1969).
(27) R. Jacquier and P. Besinet, *Bull. Soc. Chim. Fr.,* 749 (1956).
(28) P. F. Casals, *Bull. Soc. Chim. Fr.,* 253 (1963).
(29) J. Hanuise and R. R. Smolders, *Bull. Soc. Chim. Fr.,* 2139 (1967).
(30) S. Dev, *J. Indian Chem. Soc.,* **30,** 815 (1953).
(31) A. Kandiah, *J. Chem. Soc.,* 922 (1931).
(32) A. M. Islam and R. A. Raphael, *J. Chem. Soc.,* 3151 (1955).
(33) A. C. Cope and W. R. Schmitz, *J. Am. Chem. Soc.,* **72,** 3056 (1950); A. C. Cope, S. W. Fenton, and C. F. Spencer, ibid., **74,** 5884 (1952); N. Jones and H. T. Taylor, *J. Chem. Soc.,* 4017 (1959).
(34) N. Jones and H. T. Taylor, *J. Chem. Soc.,* 1342 (1961); G. Buchi, W. D. Maclead, Jr., and J. Padilla, *J. Am. Chem. Soc.,* **86,** 4438 (1964).
(35) H. C. Brown and C. P. Gary, *J. Am. Chem. Soc.,* **83,** 2952 (1961).
(36) H. O. House and G. H. Rasmusson, *J. Org. Chem.,* **28,** 31 (1963).
(37) H. J/ Dauben, Jr., and L. L. McCoy, *J. Am. Chem. Soc.,* **81,** 4863 (1959).
(38) G. D. Zuidema, E. van Tamelen, and G. Van Zyl, "Organic Syntheses", Collect. Vol. IV, Wiley, New York, N.Y., 1963, p 10.
(39) A. W. Burgstahler and I. C. Nardin, *J. Am. Chem. Soc.,* **83,** 198 (1961).

A Study of the Enamino Ketone Variant of the Robinson Annelation

Jeffrey E. Telschow and William Reusch*

Department of Chemistry, Michigan State University, East Lansing, Michigan 48824

Received October 7, 1974

The mechanism of the enamino ketone variant of the Robinson annelation has been clarified. Isomeric enamino ketones **10** and **11** were prepared by methylation of the cross- and fully conjugated enolate anions of cyclic enamino ketone **5,** and both isomers gave the same mixture of dimethyl-3,4,8,8a-tetrahydro-1,6(2*H*,7*H*)-naphthalenediones on reaction with methyl vinyl ketone. The annelation products are derived from a common trione intermediate, **13.** Efforts to alter the mechanistic course of the annelation reaction were unfruitful.

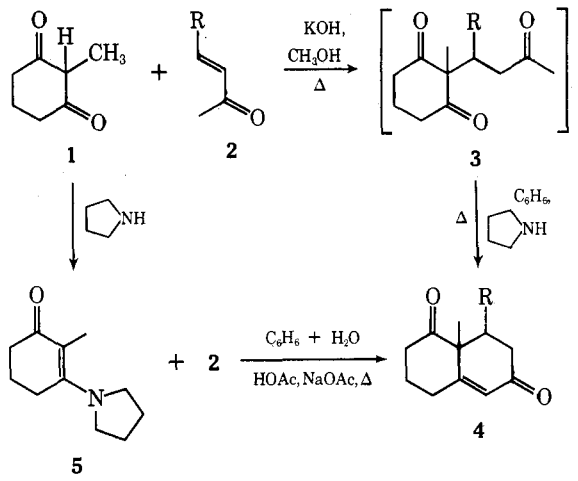
An important class of synthetic intermediates related to the Wieland–Miescher ketone[1] (**4,** R = H) can be prepared by Robinson annelations of 2-methylcyclohexane-1,3-dione with unsaturated ketones like **2.** In the procedure described by Newman and Ramachandran[2] a base-catalyzed Michael reaction generates the triketone **3,** which then undergoes aldol cyclization on treatment with pyrrolidine in benzene. A variant of this approach, developed by Coates and Shaw,[3] uses the monopyrrolidine enamine **5** derived from the 1,3-diketone reactant and employs a heterogeneous reaction medium incorporating a buffered acetic acid catalyst (Scheme I).

Coates and Shaw found that reaction of 3-penten-2-one (**2,** R = CH_3) with **5** gave predominantly the trans diketone **4** (R = CH_3) accompanied by small amounts of the cis isomer. However, by using a more polar solvent such as dimethylformamide or dimethyl sulfoxide, they were able to obtain higher proportions of the cis isomer (e.g., 1:1).

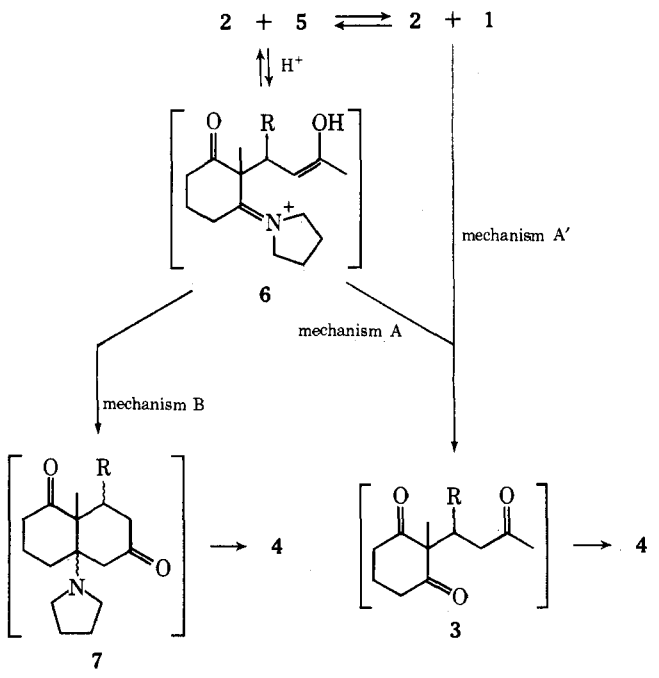
Two distinct mechanisms for this modified annelation procedure can be conceived (Scheme II).

An initial acid-catalyzed Michael addition should generate an intermediate (**6**), which could then be hydrolyzed to **3** followed by pyrrolidine-induced aldol cyclization (mechanism A). Other mechanisms leading to intermediate **3** can also be envisaged (e.g., hydrolysis of **5** to **1** followed by conventional annelation, as in mechanism A′), but for the purposes of this discussion they need not be distinguished from mechanism A. Alternatively, the immonium intermediate **6** could undergo aldol-like cyclization to a nitrogen-containing precursor (**7**) of diketone **4** (mechanism B), as

Scheme I



Scheme II

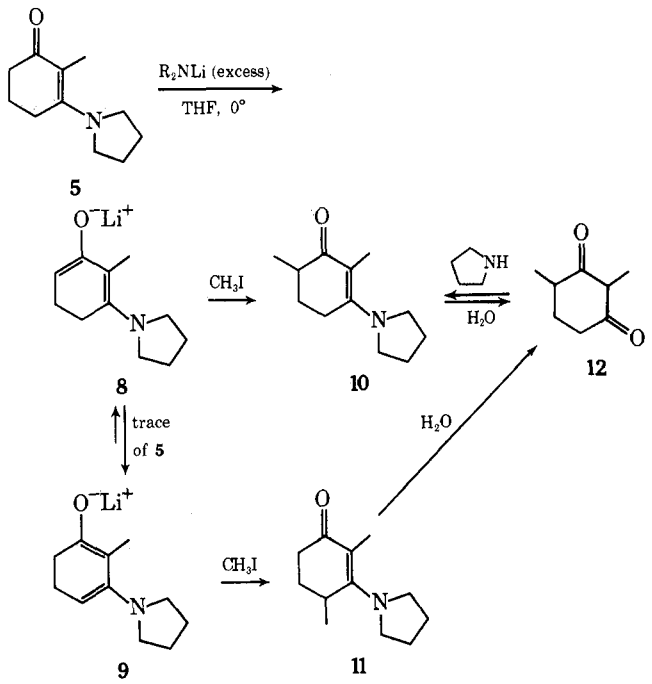


proposed by Stork et al.[10] for the reaction of the pyrrolidine enamine of cyclohexanone with methyl vinyl ketone. In mechanism A the product stereochemistry, when R = CH_3, is determined in the aldol cyclization step (i.e., by the relative rates of reaction at each of the two cyclic carbonyl groups). In mechanism B, however, the configuration of product (4) is determined in the Michael addition step—provided, of course, that the immonium function in 6 dominates the carbonyl group in its reactivity. In either case a solvent effect is needed to explain the results reported by Coates and Shaw.

We have prepared a pair of isomeric methyl homologs of **5**, which not only permit us to distinguish the mechanisms described above, but also offer—in the event mechanism B is operating—the possibility of unprecedented control in synthesizing derivatives of the Wieland–Miescher ketone.

The ability to conduct controlled alkylations of enamino ketone **5** requires selective formation of either the cross-conjugated (**8**) or fully conjugated (**9**) conjugate bases of the substrate. Since lithium isopropylcyclohexylamide (Rathke's base[4]) has been effective in preparing the kinetically favored cross-conjugated bases of cyclohexenones[5]

Scheme III



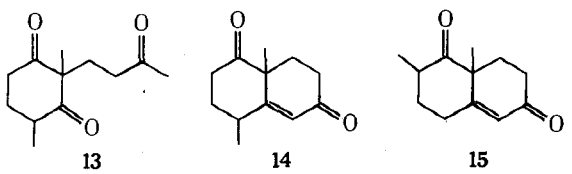
and since Stork[6] has used a similar method to generate the conjugate bases of enol ether derivatives of **1**, our initial efforts were in this direction (Scheme III).

If the amide base is maintained in excess during reaction with **5**, the cross-conjugated intermediate **8** is formed exclusively, and on methylation gives the dimethyl enamino ketone **10**. Alternatively, the presence of a slight excess of **5** during the initial stage allows equilibration of bases **8** and **9**, with the latter predominating. Methylation of **9** then gives the isomeric product **11**.

A similar γ-alkylation of an enamino ketone conjugate base was recently reported by Yoshimoto et al.[7,12] However, these workers used *n*-butyllithium as the initiating base, and our efforts to repeat this aspect of their work failed.

It is not easy to distinguish **10** and **11** by spectroscopic means (see the data in the Experimental Section). Both **10** and **11** yielded the same dimethylcyclohexane-1,3-dione (presumably **12**) on hydrolysis. Reaction of **12** with pyrrolidine was expected to take place at the less hindered carbonyl group, and the product of this reaction was assigned structure **10**.

The use of isomers **10** and **11** to distinguish mechanism A and B is straightforward. Reaction of **10** and **11** with methyl vinyl ketone (**2**, R = H) by mechanism A should yield the same mixture of Wieland–Miescher ketone derivatives **14** and **15**, since the triketone **13** is a common intermediate.

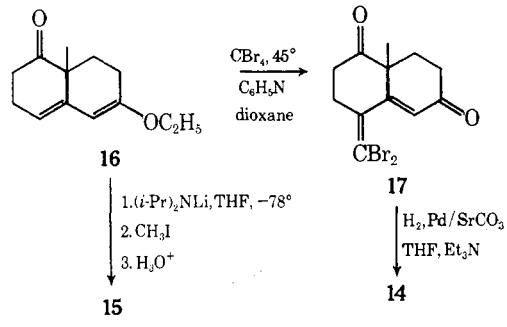


On the other hand, mechanism B predicts that **10** will be selectively transformed to **15** and **11** to **14**.

When these reactions were effected under the conditions specified by Coates and Shaw, both **10** and **11** gave the same 1:5 mixture of **14** and **15**. In the case of the reaction of methyl vinyl ketone with **11**, a small amount of another product, tentatively identified as the triketone **13** by ir and

mass spectrometry, was also obtained. Assignment of structures **14** and **15** to these products was achieved by direct comparison of these isomers with authentic samples prepared by unambiguous syntheses.

Compound **14** was prepared by reaction of the dienol ether **16**[8] with carbon tetrabromide in pyridine, followed by hydrogenation of the resulting dibromomethylene derivative **17** using a 2% $Pd/SrCO_3$ catalyst. This synthetic method is based on the work of Liisberg et al.[9] in the preparation of 6-methyl-Δ^4-3-keto steroids.



Methylation of **16**, using lithium diisopropylamide and methyl iodide, afforded **15** after hydrolysis of the intermediate methylated dienol ether.

The experiments described here clearly show that this annelation proceeds by mechanism A under the reaction conditions defined by Coates and Shaw. Nevertheless, it would be very useful to develop conditions for effecting an equivalent annelation by mechanism B, since the regioselective control provided by such a pathway is desirable. However, efforts to effect an acid-catalyzed reaction of enamino ketone **5** with methyl vinyl ketone, in a variety of anhydrous solvents ranging in polarity from benzene to hexamethylphosphoric triamide, were unsuccessful. Even with elevated temperatures and prolonged reaction times, very little reaction occurred, and the amount of Wieland–Miescher ketone in the neutral products was always very small.

Experimental Section

Preparation of 2,6-Dimethyl-3-(1-pyrrolidyl)-2-cyclohexen-1-one (10). A. To a chilled (0°) solution of 0.31 ml (2.2 mmol) of diisopropylamine in 1 ml of dry tetrahydrofuran (THF) under dry nitrogen was added 1.0 ml of a 2.15 *M* solution of *n*-butyllithium in hexane. To the resulting solution of lithium diisopropylamide (LDIA) was added a solution of 358 mg (2.0 mmol) of **5** (prepared by the method of Coates and Shaw[3] and recrystallized from ether, mp 37–39°) in 1 ml of THF. This enolate solution was stirred at 0° for 30 min, following which 0.15 ml (2.4 mmol) of methyl iodide was added. The resulting mixture was warmed to room temperature, stirred for 15 min, and then concentrated under reduced pressure. An ethyl acetate solution of the residue was washed with water and brine, dried (Na_2SO_4), and evaporated under reduced pressure to give 351 mg (91%) of **10** as a light brown oil which crystallized when chilled. Several recrystallizations of **10** from ether gave colorless, deliquescent crystals: mp 27–35°; ir (neat) 1540, 1605 cm^{-1}; NMR ($CDCl_3$) δ 1.04 (d, J = 6.5 Hz, 3), 1.2–2.3 (m, 7), 1.86 (s, 3), 2.50 (br t, 2), 3.45 (m, 4); uv max (95% EtOH) 317 nm (ϵ 26,300)

Anal.[11] Calcd for $C_{12}H_{19}NO$: C, 74.57; H, 9.91; N, 7.25. Found: C, 74.66; H, 10.01; N, 7.29.

B. A compound having the same spectroscopic properties as **10** was produced by the reaction of pyrrolidine with dione **12**. A solution of 65 mg of **12** (produced by hydrolysis of 97 mg of **10** or **11** in 5% HCl at 100° for 15 min) in 3 ml of benzene and 0.075 ml of pyrrolidine was refluxed through a Dean-Stark trap for 75 min and then concentrated under reduced pressure. An NMR spectrum of the crude product was superimposable with that of **10** produced by the methylation of **5**.

Preparation of 2,4-Dimethyl-3-(1-pyrrolidyl)-2-cyclohexen-1-one (11). To a solution of 4.6 mmol of LDIA in 2.5 ml of THF under nitrogen at 0° was added a solution of 895 mg (5.0 mmol, 8.7% excess) of **5** and 2.5 ml of dry hexamethylphosphoric triamide in 2.5 ml of THF. The resulting enolate solution was stirred at room temperature for 21 hr and then at 40° for 3 hr. After this solution was cooled to 0°, 0.35 ml (5.6 mmol) of methyl iodide was added, and the mixture was allowed to return to room temperature for 1.5 hr. Work-up as described for the preparation of **10** gave 986 mg of yellow oil. Column chromatography (silica gel, 1:10 methanol–ether) of 748 mg of this oil gave 403 mg (63%) of **11**. Several recrystallizations from ether gave colorless, deliquescent crystals: mp 27–35°; ir (neat) 1540, 1605 cm^{-1}; NMR ($CDCl_3$) δ 1.20 (d, J = 7 Hz, 3), 1.5–2.2 (m, 6), 1.91 (s, 3), 2.36 (br t, 2), 2.55 (m, 1), 3.56 (m, 4); uv max (95% EtOH) 323 nm (ϵ 26,300).

Anal. Calcd for $C_{12}H_{19}NO$: C, 74.57; H, 9.91; N, 7.25. Found: C, 74.56; H, 9.95; N, 7.18.

Preparation of 6-Ethoxy-8a-methyl-3,7,8,8a-tetrahydro-1(2*H*)-naphthalenone (16). The procedure of Boyce and Whitehurst[8] was modified to give better yields. A solution consisting of 35 ml of benzene, 9 ml (54 mmol) of distilled triethyl orthoformate, 15 mg of *p*-toluenesulfonic acid, and 8.9 g (50 mmol) of Wieland–Miescher ketone **4**, R = H, was stirred under nitrogen at room temperature for 4 hr. The reaction mixture was neutralized with three drops of triethylamine, diluted with 35 ml of ether, and extracted successively with 15 ml of 10% $NaHCO_3$, 20 ml of water, and 20 ml of brine. After being dried over Na_2SO_4, the solution was evaporated in vacuo to give a yellow oil which could be used without further purification.

Preparation of 4-Dibromomethylene-8a-methyl-3,4,8,8a-tetrahydro-1,6(2*H*,7*H*)-naphthalenedione (17). A solution containing 618 mg (3.0 mmol) of dienol ether **16**, 2.00 g (6.0 mmol) of carbon tetrabromide, 3 ml of pyridine, and 3 ml of dioxane was maintained at room temperature under nitrogen for 24 hr and then heated at 45° for 24 hr. The resulting dark solution was filtered, concentrated under reduced pressure, acidified, and extracted with ethyl acetate. The organic extract was washed successively with 6 *N* HCl, 10% $NaHCO_3$, and brine before being dried over Na_2SO_4. Evaporation of the solvents in vacuo left 954 mg of a brown semisolid which was chromatographed (silica gel, ether) to yield 514 mg (50%) of brown **17**. Several recrystallizations from methylene chloride–ether gave white needles: mp 85–86°; ir (KBr) 1565, 1610, 1665, 1720 cm^{-1}; NMR ($CDCl_3$) δ 1.36 (s, 3), 1.9–2.8 (m, 8), 6.25 (s, 1); uv max (95% EtOH) 260 nm (shoulder ϵ 5700), 287 (7600),

Anal. Calcd for $C_{12}H_{12}Br_2O_2$: C, 41.41; H, 3.48. Found: C, 41.44; H, 3.38.

Preparation of 4,8a-Dimethyl-3,4,8,8a-tetrahydro-1,6-(2*H*,7*H*)-naphthalenedione (14). To a suspension of 800 mg of 2% $Pd/SrCO_3$ catalyst (saturated with hydrogen) in 6 ml of dry THF was added a solution of 1.740 g (5.0 mmol) of **17** and 1.4 ml (10 mmol) of triethylamine in 8 ml of THF. The mixture was stirred vigorously and allowed to absorb 376 ml (15.0 mmol) of hydrogen at atmospheric pressure. After filtration, the catalyst was washed well with THF and the filtrate was concentrated. An ether solution of the residue was extracted with water and brine, dried (Na_2SO_4), and evaporated to give 987 mg of a yellow oil. Column chromatography (silica gel, 30% ethyl acetate–hexane) gave 312 mg (32%) of light yellow **14** as an epimeric mixture, from which the more stable equatorial methyl epimer could be isolated after equilibration of the product in a CCl_4 solution of HCl. Recrystallization from ether–petroleum ether gave white needles: mp 28–34°; ir (KBr) 1605, 1665, 1710 cm^{-1}; NMR (CCl_4) δ 1.18 (d, J = 6.5 Hz, 3), 1.39 (s, 3), 1.5–2.9 (m, 9), 5.60 (d, J = 2 Hz, 1).

Anal. Calcd for $C_{12}H_{16}O_2$: C, 74.97; H, 8.39. Found: C, 74.83; H, 8.31.

Preparation of 2,8a-Dimethyl-3,4,8,8a-tetrahydro-1,6-(2*H*,7*H*)-naphthalenedione (15). To a solution of 0.50 mmol of LDIA in 0.5 ml of THF under nitrogen at −78° was added a solution of 103 mg (0.50 mmol) of dienol ether **16** in 0.7 ml of THF. The resulting solution was stirred at −78° for 20 min and then treated with 0.035 ml (0.60 mmol) of methyl iodide. This solution was stirred at −78° for 10 min and at room temperature for 30 min and finally diluted with water and ether. The organic phase was washed successively with 5% HCl, water, and brine, giving 103 mg of methylated dienol ether after evaporation of the solvent in vacuo. This crude product was hydrolyzed for 3 hr at room temperature in a solution containing 1 ml of THF, 1 drop of 6 *N* HCl, and several drops of water. Work-up as usual gave 83 mg (87%) of **15** which, after purification by GLC (10-ft 4% QF-1, 200°), was obtained as a yellow oil: ir (neat) 1615, 1670, 1710 cm^{-1}; NMR (CCl_4) δ 1.02 (d, J = 6.5 Hz, 3), 1.41 (s, 3), 1.5–3.0 (m, 9) 5.61 (m, 1).

Anal. Calcd for $C_{12}H_{16}O_2$: C, 74.97; H, 8.39. Found: C, 75.04; H, 8.40.

Reaction of 10 with Methyl Vinyl Ketone. To a solution consisting of 0.13 ml of water, 0.13 ml of acetic acid, and 62 mg of sodium acetate was added 0.100 ml of methyl vinyl ketone and 215 mg (1.11 mmol) of **10** in 1 ml of benzene. The mixture was refluxed under nitrogen for 4 hr, cooled, diluted with benzene, and extracted with 5% HCl. The organic phase was washed successively with water, 10% $NaHCO_3$, and brine, dried (Na_2SO_4), and evaporated in vacuo to give 179 mg of a yellow oil. GLC analysis of (5-ft 4% QF-1, 175°) of this oil showed **14** and **15** in a ratio of about 1:5 by comparison of the retention times with those of authentic samples.

Reaction of 11 with Methyl Vinyl Ketone. To the same aqueous acetic acid solution used above was added 0.070 ml of methyl vinyl ketone and 193 mg (1.0 mmol) of **11** in 1 ml of benzene. The mixture was refluxed for 4.5 hr and worked up as above to give 142 mg of a yellow oil. GLC analysis of this oil showed **14** and **15** in a ratio of about 1:5, and a small amount of a third component which was isolated by preparative GLC (10-ft 4% QF-1, 190°) and tentatively identified as the trione **13** by its ir [(CCl_4) 1695, 1720 cm^{-1}] and mass spectra (mol wt 210).

Acknowledgment. We thank the National Institutes of Health for their support of this work (Grant 2 R01 AM 10849-08) and Mrs. Lorraine Guile for her assistance in obtaining mass spectra.

Registry No.—**2** (R = H), 78-94-4; **4** (R = H), 42576-97-6; **5**, 53940-63-9; **10**, 53940-64-0; **11**, 53940-65-1; **12**, 20990-14-1; *cis*-**14**, 53940-66-2; *trans*-**14**, 53940-67-3; **15**, 53940-68-4; **16**, 53940-69-5; **17**, 53940-70-8; pyrrolidine, 123-75-1; carbon tetrabromide, 558-13-4.

References and Notes

(1) P. Wieland and K. Miescher, *Helv. Chim. Acta*, **33**, 2215 (1950).
(2) S. Ramachandran and M. S. Newman, "Organic Syntheses," Collect. Vol. V, Wiley, New York, N.Y., 1973, p 486.
(3) R. M. Coates and J. E. Shaw, *J. Am. Chem. Soc.*, **92**, 5657 (1970).
(4) M. W. Rathke and A. Lindert, *J. Am. Chem. Soc.*, **93**, 2318 (1971).
(5) R. A. Lee, C. McAndrews, K. M. Patel, and W. Reusch, *Tetrahedron Lett.*, 965 (1973).
(6) G. Stork and R. L. Danheiser, *J. Org. Chem.*, **38**, 1775 (1973).
(7) M. Yoshimoto, N. Ishida, and T. Hiraoka, *Tetrahedron Lett.*, 39 (1973).
(8) B. C. Boyce and J. S. Whitehurst, *J. Chem. Soc.*, 2680 (1960).
(9) S. Liisberg, W. O. Godtfredsen, and S. Vangedal, *Tetrahedron*, **9**, 149 (1960).
(10) G. Stork, A. Brizzolara, H. Landesman, J. Szmuszkovicz, and R. Terrell, *J. Am. Chem. Soc.*, **85**, 207 (1963).
(11) Microanalyses are by Spang Microanalytical Laboratory, Ann Arbor, Mich.
(12) Note Added in Proof. The general synthetic usefulness of γ-alkylations of enamino ketone conjugate bases has been convincingly demonstrated very recently by T. A. Bryson and R. B. Gammill, *Tetrahedron Lett.* 3963 (1974).

A Novel Chlorination of the Adamantyl System by Silver Salts in Carbon Tetrachloride

Arthur L. Schwartz[1] and Sung Moon*

Department of Chemistry, Adelphi University, Garden City, New York 11530

Received April 9, 1974

Silver acetate reacts with 1-bromoadamantane in carbon tetrachloride to produce 3-chloro-1-adamantyl acetate as the major product. Silver bromide acts on adamantane in CCl_4 to give a low yield of 1-chloroadamantane. Bromine, phosgene, bromotrichloromethane, and hydrogen chloride are significant by-products. Addition of silver acetate to the silver bromide greatly increases the yield of chlorinated adamantanes. Similar treatment of 1-adamantyl acetate with these same silver salts in CCl_4 gives mainly 3-chloro-1-adamantyl acetate. Silver bromide is the primary initiator of these free-radical chlorinations but, unlike many radical processes, oxygen is a requirement for its propagation. Catalysis by silver acetate was traced to the intermediacy of bromine chloride which can function as an efficient initiator for the carbon tetrachloride chlorination of adamantane.

In connection with concurrent studies in the field of adamantane chemistry, we needed an authentic sample of 1-adamantyl acetate. Although we were aware of its synthesis[2] from the alcohol by treatment with acetic anhydride, production of the acetate from 1-bromoadamantane and silver acetate in carbon tetrachloride appeared to be a feasible alternative to that procedure.

It was observed, however, that after refluxing for 20 hr and standing for 4 days, the principal product was 3-chloro-1-adamantyl acetate (**2**) with the anticipated 1-adamantyl acetate (**3**) forming in considerably smaller amounts (eq 1).

In addition to typical acetate absorptions at 1740 and 1240 cm^{-1} the infrared spectrum of chloroacetate **2** showed a band at 840 cm^{-1} attributable to C–Cl stretching. An nmr spectrum displayed five peaks at τ 7.63, 7.74, 7.93, 8.10, and 8.40 corresponding to 2, 2, 8, 3, and 2 protons, respectively. Structure **2** was further confirmed by a spontaneous positive test toward alcoholic silver nitrate reagent.

Since 1-adamantyl acetate was identified as a product, attention focused on silver acetate or the silver bromide by-product as species which might be involved in the conversion of acetate **3** to the chloroacetate **2**.

A review of the literature did not reveal examples of the direct halogenation of a hydrocarbon by silver acetate initiation in CCl_4. In fact, the tendency for silver acetate to ho-