The Reactions of 4-Bromocyclohexadienones with Nucleophiles Containing Phosphorus and Sulfur[1]

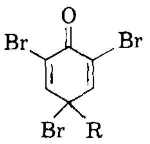
BERNARD MILLER

Chemical Research Laboratories, Agricultural Division, American Cyanamid Company, Princeton, New Jersey

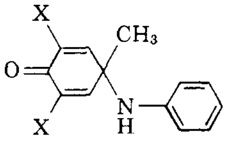
Received September 14, 1962

Dialkyl phosphonates reduce 4-bromocyclohexadienones to phenols after a short induction period. Trialkyl phosphites react almost instantaneously with 4-bromocyclohexadienones to give dialkyl phosphate esters of the phenols from which the cyclohexadienones were formed. A mechanism is proposed for these reactions, and for the Perkow reaction, involving initial attack by phosphorus at a halogen atom. Sodium thiophenoxide and dibutyl sulfide reduce 4-bromocyclohexadienones to phenols. The thiophenoxide anion is oxidized to the disulfide stage during the reaction, and the sulfide to the sulfoxide.

The reactions of 4-halocyclohexadienones (I) with nucleophilic reagents are particularly interesting subjects for study, since almost every position on the cyclohexadienone molecule is a possible point for attack by a nucleophilic reagent.



Ia. R = CH_3
b. R = Br



II

Comparatively few such reactions have been studied. Several nucleophilic agents, including iodide ions[2] and metallic tin,[3] attack either the bromine or the oxygen atom of a bromocyclohexadienone—the two modes of attack are experimentally indistinguishable[4]—to yield the parent phenol. Diethylzinc similarly reduces the dienones to the phenols, but the position of attack by this reagent is known, since ethyl bromide is obtained.[2] Aromatic amines either reduce the dienone to the phenol[5] or displace a bromide ion to give 4-arylaminocyclohexadienones (II),[6] depending on the structure of the dienone, while lead diacetate will replace a *gem*-dibromo group by a carbonyl function.[7]

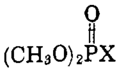
No reactions of halocyclohexadienones with nucleophiles containing phosphorus or sulfur have previously been reported. Several such reactions have now been studied, in the hope of clarifying some aspects of the similar reactions of α-halo ketones.

Reactions with Phosphorus Derivatives.—Both dimethyl phosphonate (IIIa) and its sodium salt (IIIb) react with Ia to give 2,6-dibromo-4-methylphenol in high yield. When the reactions were run in methanol solution, dimethyl phosphorobromidate (IIIc) was isolated as its methyl ester.

Dimethyl phosphonate reacts with Ia in benzene only after a ten minute induction period, which is followed by a fast, exothermic reaction. The induction period does not seem to be due to the initiation of free radical chains, since no decrease in the induction period is observed when benzoyl peroxide is added. Changing the solvent from benzene to methanol reduces the induction period from ten minutes to thirty seconds.

The autocatalytic nature of the reaction can readily be explained as due to a slow tautomerism of the pentavalent phosphonate (which lacks a highly nucleophilic center) to its more reactive phosphite form (IV) which then reacts rapidly with Ia. The tautomeric shift is catalyzed by traces of hydrogen bromide produced by hydrolysis of the phosphoryl bromide (IIIc). (It is almost impossible to free Ia completely of traces of water.) The reaction thus proceeds much more rapidly in methanol than in benzene, not only because the polar solvent provides a more favorable medium for an ionic reaction, but also because the production of acid from the methanolysis of IIIc accelerates the reaction.[8]

Dimethyl phosphonate could *a priori* reduce I to the phenol stage either by attack at the carbonyl oxygen or at the bromine atom. The immediate product of attack at the carbonyl oxygen, however, would be the conjugate acid of the dialkyl aryl phosphate Vb.

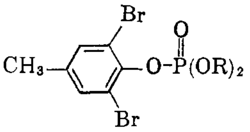


$$(CH_3O)_2\overset{O}{\overset{\|}{P}}X$$

III
a. X = H
b. X = Na
c. X = Br

$(CH_3O)_2POH$

IV



Va. R = Et
b. R = Me

Since Vb, as will be seen, is a stable, easily isolated molecule, inert to the action of anhydrous hydrogen bromide in benzene, it is clear that Vb cannot be an intermediate in the reaction of Ia and IIIa. The phosphorus atom must, therefore, have attacked the bromine atom of the 4-bromocyclohexadienone.

Trialkyl phosphites, unlike dialkyl phosphonates, react almost instantaneously with Ia. The reaction in benzene or ether is highly exothermic, and the yellow cyclohexadienone color disappears simultaneously with the addition of the last drops of the phosphite. The products of these reactions, obtained in quantitative yields, were the dialkyl aryl phosphates V. The structures of V were clearly indicated by the absence of carbonyl or hydroxyl peaks and the presence of strong P=O peaks at 7.8 μ in their infrared spectra, and were

---

[1] Part of this work has been published as a preliminary communication; B. Miller, *J. Org. Chem.*, **26**, 4781 (1961).

[2] J. H. Kastle and A. S. Loevenhart, *Am. Chem. J.*, **27**, 32 (1902).

[3] R. Benedikt, *Ann.*, **199**, 127 (1879).

[4] The reduction of substituted ketones by metals has been postulated to proceed by displacement on the carbonyl oxygen—*e.g.*, R. B. Woodward *et al.*, *J. Am. Chem. Soc.*, **74**, 4223 (1952).

[5] I. Suknerich and S. Budnitzki, *J. prakt. Chem.* (2), **138**, 18 (1933).

[6] K. Fries and G. Oehmke, *Ann.*, **462**, 1 (1928).

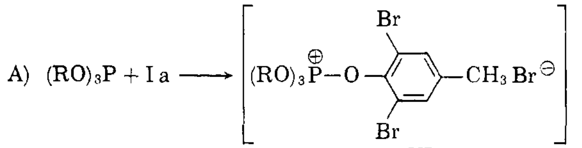
[7] J. Thiele and H. Eichwede, *Ber.*, **33**, 673 (1900).

[8] The acid-catalyzed tautomerism of dialkyl phosphonates to dialkyl hydrogen phosphites has recently been demonstrated by tracer techniques; Z. Luz and B. Silver, *J. Am. Chem. Soc.*, **83**, 4518 (1961).

confirmed by the synthesis of Va from diethyl phosphorochloridate and sodium 2,6-dibromo-4-methylphenoxide.

The preparation of V from Ia and a phosphite may be considered a vinylog of the Perkow synthesis[9] of an enol phosphate from an α-halo carbonyl compound and a trialkyl phosphite. It has been suggested[9] that the Perkow reaction proceeds by initial addition of the phosphite molecule to the carbonyl carbon. This, however, cannot be the case for the reactions of Ia, since the markedly increased rates of reaction of trialkyl phosphites with Ia, compared to their reactions with simple α-halo ketones,[10] show that the transition states for the reactions of the cyclohexadienones have acquired some of the aromatic character of the products. Addition of a phosphite to a carbonyl group of Ia might be expected, in fact, to be slower than addition to a typical ketone, since it would be necessary to break the conjugation between the carbonyl group and the double bonds.

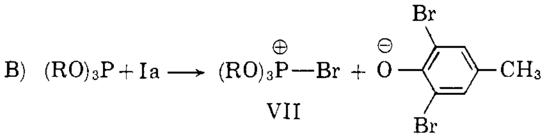
Two simple reaction paths can be written for the formation of V: Attack at the carbonyl oxygen (path A) and at the bromine atom (path B).



A) (1a)

VI

$$\text{VI} \longrightarrow \text{V} + \text{RBr} \qquad (1b)$$



B) (2a)

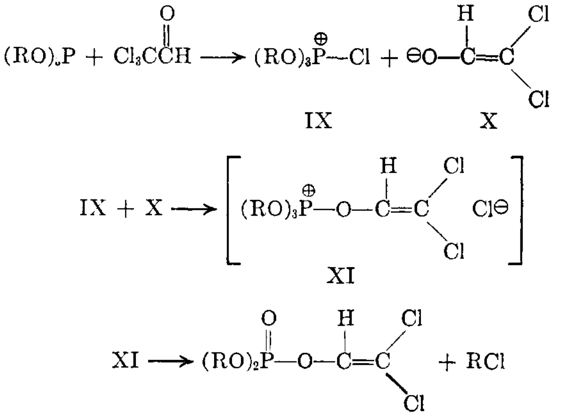
VII VIII

$$\text{VII} + \text{VIII} \longrightarrow \text{VI} \qquad (2b)$$

$$\text{VI} \longrightarrow \text{V} + \text{RBr} \qquad (2c)$$

Direct attack of a phosphite molecule on a carbonyl oxygen (step 1a) has been observed by Ramirez and his collaborators in the quinone series,[11] while step 2a resembles that observed for the reaction of dialkyl phosphonates with Ia (see above). As was pointed out above, it is probable that dialkyl phosphonates do not react with Ia in the phosphonate form, but first tautomerize to the more reactive dialkyl hydrogen phosphite. Since there seems to be no reason to postulate different reaction paths for dialkyl hydrogen phosphites and for trialkyl phosphites, we prefer reaction sequence B over sequence A.

A scheme similar to sequence B can be written for the normal Perkow reaction, and is, in fact, consistent with all the known facts about the Perkow reaction. In particular, all substituents which would tend to stabilize enolate ions increase the rate of Perkow reactions,[9] as would be predicted from reaction sequence B. The reaction of trialkyl phosphites with chloral, according to this scheme, would proceed as shown in equations 3a–c.



$$(RO)_3P + Cl_3C\overset{O}{\overset{\|}{C}}H \longrightarrow (RO)_3\overset{\oplus}{P}-Cl + {}^{\ominus}O-\overset{H}{\overset{|}{C}}=CCl_2 \qquad (3a)$$

IX X

$$\text{IX} + \text{X} \longrightarrow \left[(RO)_3\overset{\oplus}{P}-O-\overset{H}{\overset{|}{C}}=CCl_2 \quad Cl^{\ominus}\right] \qquad (3b)$$

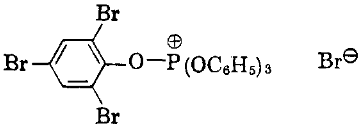
XI

$$\text{XI} \longrightarrow (RO)_2\overset{O}{\overset{\|}{P}}-O-\overset{H}{\overset{|}{C}}=CCl_2 + RCl \qquad (3c)$$

A similar view of the Perkow reaction has recently been expressed by Speziale and Smith.[12]

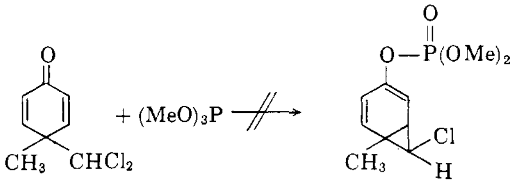
Trimethyl phosphite reacts with Ia in ethanol solution to give 2,6-dibromo-4-methylphenol and ethyl dimethyl phosphate. This reaction may result from the reaction of ethanol with VII in scheme B or with VI in scheme A or B. An analogous reduction of quinone to hydroquinone by trialkyl phosphites in alcohol solution has been observed.[11]

Triphenyl phosphite reacts with Ib to give a white, very hygroscopic solid which was assigned structure XII on the basis of its mode of preparation, physical properties, ionic bromide analysis, and hydrolysis to triphenyl phosphate and tribromophenol in water or ethanol. No indication of hydrolysis to phenol and diphenyl-2,4,6-tribromophenyl phosphate could be observed. This selectivity is probably due to a combination of the relief of steric strain caused by the two *ortho* bromine atoms, and the greater stability of the tribromophenoxide anion as compared to a phenoxide anion. XII is the first tetraäryloxy phosphonium salt to be reported with more than one type of aryl residue per molecule. The previous synthesis of these salts by halogenation of triaryl phosphites[13] is unsuited to the preparation of mixed salts such as XII.



XII

Since I reacts so rapidly with trialkyl phosphites, we hoped that a homologous reaction would occur at a measurable rate. We could not detect any reaction between XIII and trimethyl phosphite, however, even on prolonged refluxing in the pure phosphite.



XIII

---

[9] See F. W. Lichtenthaler, *Chem. Rev.*, **61**, 607 (1961), for a comprehensive discussion and other references.

[10] Bromoacetone is typically heated to *ca.* 100° to induce reaction with trimethyl phosphite (ref. 9).

[11] (a) F. Ramirez and S. Dershowitz, *J. Am. Chem. Soc.*, **78**, 5614 (1956); (b) F. Ramirez and S. Dershowitz, *ibid.*, **81**, 587 (1959).

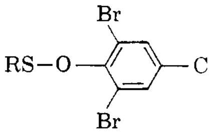
[12] A. J. Speziale and L. R. Smith, *ibid.*, **84**, 1868 (1962).

[13] H. N. Rydon and B. L. Tonge, *J. Chem. Soc.*, 3043 (1956).

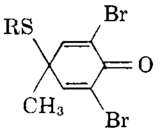
2-Acetoxy-2,4,6-trimethylcyclohexadien-1-one was recovered unchanged after several hours refluxing with triethyl phosphite, showing that a very good leaving group must be present for reaction to occur, in spite of the highly exothermic nature of the reaction.

Sulfur Compounds.—In view of the successful preparation of 4-arylaminocyclohexadienones by displacement of bromide ions from Ia,[6] it was hoped that the more nucleophilic thiophenoxide ion would give at least a small yield of a 4-thiophenylcyclohexadienone on reaction with Ia. No trace of carbonyl could be discerned at the end of the reaction, however, and the only products obtained were diphenyl disulfide and 2,6-dibromo-4-methylphenol. Similar results were obtained when potassium O,O-diethyl phosphorodithioate was used as the nucleophile.

Three possible reaction paths may be considered for the reaction of thiol salts with I: (a) reaction at the bromine atom to give a sulfenyl bromide, which then reacts with another thiol anion to form the disulfide; (b) reaction at the carbonyl oxygen to give the sulfenate ester (XIV), followed by reaction with a thiol anion to form the disulfide; or (c) formation of the desired cyclohexadienone (XV), with subsequent reduction to the disulfide by a thiol anion.



XIV



XV

The formation of a disulfide from a thiol anion and a diaryl sulfenate (path B) presumably occurs during the formation of diphenyl disulfide from benzenesulfenyl chloride and sodium phenoxide.[14] The cleavage of a C—S bond to form an S—S bond (path C) has no known analogies, but might well occur in this energetically very favorable case. No clear choice can be made among reactions A—C, but path A is preferred by analogy with the reactions of phosphorus esters.

When Ia and a thiol salt reacted in a 1:1 mole ratio, one mole of 2,6-dibromo-4-methylphenol was still obtained, showing that disulfides were capable of reducing Ia to the phenol. The sulfur containing products of these reactions were not isolated.

The reaction of I with dibutyl sulfide proceeded smoothly and rapidly, and the products were again free of carbonyl absorption. Dibutyl sulfoxide was isolated in good yield, together with 2,6-dibromo-4-methylphenol and 2,4,6-tribromophenol from Ia and Ib, respectively.

Experimental[15]

Reaction of 2,4,6-Tribromo-4-methylcyclohexadien-1-one (Ia) with Dimethyl Phosphonate. (a) In Benzene.—Ia[6] (5.4 g., 0.0159 mole) was suspended and stirred rapidly in 25 ml. of benzene, and dimethyl phosphonate (2.11 g., 0.0191 mole) was added. No apparent reaction occurred at first, but after 10 min., the yellow color changed to orange and the mixture became rather warm. After 3 more minutes the solid cyclohexadienone had dissolved and the color had disappeared. After stirring for an additional 30 min., the solution was washed with water, dried over magnesium sulfate, and evaporated to give 3.8 g. (0.0143 mole, 90%) of 2,6-dibromo-4-methylphenol, identified by melting point and infrared spectrum.

(b) In Presence of Benzoyl Peroxide.—Ia (3.0 g., 0.00869 mole) and benzoyl peroxide (0.30 g., 0.00124 mole) were stirred in 15 ml. of benzene. Dimethyl phosphonate (1.0 g., 0.010 mole) was added. After stirring for 10 min., the color gradually deepened to a light orange, and the solution warmed slightly. After stirring for a few more minutes, the solid Ia completely dissolved and the color quickly changed to a very faint yellow. The solution was discarded.

(c) In Methanol.—Ia (6.0 g., 0.01738 mole) was suspended in 30 ml. of methanol and dimethyl phosphonate (2.0 g., 0.020 mole) was added. After stirring for 30 sec. the solution became quite warm and turned orange, and the solid Ia dissolved. The color disappeared in an additional 10 sec. The solvent was evaporated and the product distilled at 1.50-mm. pressure, to give 1.82 g. of trimethyl phosphate (0.013 mole, 75%) and 4.13 g. of 2,6-dibromo-4-methylphenol (0.0155 mole, 89%).

Reaction of Sodium Dimethyl Phosphonate with Ia.—To a solution of 1.50 g. of sodium methoxide (0.0278 mole) in 50 ml. of methanol was added 3.0 g. of dimethyl phosphonate (0.0273 mole). The solution was added over a 3-min. period to a stirred suspension of Ia (7.90 g., 0.0229 mole) in 50 ml. of benzene. After stirring for 15 min., the solvent was evaporated, the residue extracted with chloroform, and the chloroform evaporated to give 8.5 g. of a yellow oil. The product was distilled at 1.75 mm., to give 2.7 g. of trimethyl phosphate (0.0193 mole, 71%) and 4.7 g. of 2,6-dibromo-4-methylphenol (0.0170 mole, 74%).

Preparation of Diethyl 2,6-Dibromo-4-methylphenyl Phosphate (Va). (a) Reaction of Triethyl Phosphite with Ia.—Ia (9.60 g., 0.0278 mole) was suspended and stirred in 50 ml. of benzene. A solution of triethyl phosphite (4.60 g., 0.0277 mole) in 25 ml. of benzene was added in a 2–3 min. period. The mixture refluxed vigorously, and the solid Ia dissolved. After stirring for 10 min., the benzene was evaporated, to give 10.8 g. (0.0268 moles, 97%) of crude product as a yellow liquid, n^{25}_{D} 1.5380. After chromatography on neutral alumina and evaporative distillation at 0.001 mm., diethyl 2,6-dibromo-4-methylphenyl phosphate was obtained as a colorless liquid. Its infrared spectrum was identical with that of the crude reaction product.

Anal. Calcd. for $C_{11}H_{15}O_4Br_2P$: C, 32.86; H, 3.76; Br, 39.75; P, 7.71. Found: C, 33.13, 33.02; H, 4.09, 3.93; Br, 39.74, 39.51; P, 7.84, 7.87.

(b) Reaction of Sodium 2,6-Dibromo-4-methylphenoxide with Diethyl Phosphorochloridate.—2,6-Dibromo-4-methylphenol (11.5 g., 0.0434 mole) and sodium methoxide (2.34 g., 0.0434 mole) were dissolved in 100 ml. of methanol. The solvent was evaporated on a rotary evaporator to give 12.8 g. of sodium 2,6-dibromo-4-methylphenoxide, which was dissolved in 100 ml. of methyl isobutyl ketone. The solution was heated to 42° and a solution of diethyl phosphorochloridate (7.5 g., 0.0435 mole) in 20 ml. of methyl isobutyl ketone was added slowly. The temperature rose rapidly to 57° and a white precipitate formed. The mixture was held at 57° for 1 hr., cooled, and centrifuged free of salt. Evaporation of the solvent gave 14.0 g. (0.0348 mole, 80%) of IVa, whose infrared spectrum was identical with that prepared by method a.

Preparation of Dimethyl 2,6-Dibromo-4-methylphenyl Phosphate (Vb).—Trimethyl phosphite and Ia reacted as described above for triethyl phosphite to give a 91% yield of Vb. The analytical sample was distilled at 0.005 mm. and 112°.

Anal. Calcd. for $C_9H_{11}O_4Br_2P$: C, 28.90; H, 2.97; Br, 42.73; P, 8.28. Found: C, 29.00, 29.15; H, 2.98, 3.13; Br, 43.07, 43.01; P, 7.98, 8.09.

Reaction of Trimethyl Phosphite with Ia in Ethanol.—Ia (10.2 g., 0.0295 mole) was suspended and stirred in 50 ml. of ethanol. A solution of trimethyl phosphite (3.75 g., 0.0302 mole) in 10 ml. of ethanol was added. A mild reaction occurred, and after 2 min. the solution was colorless and the Ia had dissolved. Evaporation of the solvent left 11.0 g., of yellow oil, whose infrared spectrum showed no trace of Vb. The oil was dissolved in methylene chloride, and the solution washed with 5% sodium hydroxide solution, dried over magnesium sulfate, and evaporated to give 2.2 g. (0.0143 mole, 47%) of ethyl dimethyl phosphate, whose infrared spectrum and vapor-phase chromatography retention time were identical with those of a sample prepared by ethanolysis of dimethyl phosphorochloridate. Acidification of the base washes, extraction with methylene chloride, drying over magnesium sulfate, and evaporation of the solvent left 6.0 g. (0.0225 mole, 77%) of 2,6-dibromo-4-methylphenol.

---

(14) H. Lecher, *Ber.*, **58**, 409 (1925).

(15) Microanalyses by Galbraith Microanalytical Laboratories, Knoxville, Tenn.

Preparation of Triphenoxy-2,4,6-tribromophenoxy Phosphonium Bromide (XII).—2,4,4,6-Tetrabromocyclohexadien-1-one (9.4 g., 0.0229 mole) was suspended and stirred in 50 ml. of benzene, and a solution of triphenyl phosphite (7.4 g., 0.0239 mole) in 10 ml. of benzene was added. The reaction mixture became quite warm, the solid dienone dissolved, and then a second oily phase separated. After stirring for 30 min., the benzene layer was decanted, and the residual oil triturated with anhydrous ether. The product crystallized to a gummy yellow soil which was washed carefully with anhydrous ether and stored under ether or benzene. The yield was 12.5 g. (0.0177 mole, 75%).

Anal. Calcd. for $C_{24}H_{17}O_4Br_4P$: Ionic Br, 11.1. Found: Ionic Br, 11.3.

Attempted Reaction of Trimethyl Phosphite with 4-Methyl-4-dichloromethylcyclohexadien-1-one (XIII).—XIII (3.5 g.) was dissolved in 10 ml. of toluene, and trimethyl phosphite (7 ml.) was added. The solution was refluxed for 23 hr., and the solvent and trimethyl phosphite evaporated to give 3.5 g. of recovered XIII.

Attempted Reaction of Triethyl Phosphite with 2-Acetoxy-2,4,6-trimethylcyclohexadien-1-one.—A solution of triethyl phosphite (3.70 g., 0.0223 mole) and 2-acetoxy-2,4,6-trimethylcyclohexadien-1-one[16] (4.0 g., 0.0217 mole) in 20 ml. of benzene was refluxed for 3 hr. On evaporation of the solvent the residue was recrystallized from ether–petroleum ether to give 3.2 g. of the starting dieneone. Evaporation of the solvent from the mother liquor left 1.7 g. of yellow liquid, which showed strong unsaturated ketone and ester peaks in its infrared spectrum. It was not investigated further.

Reaction of Sodium Thiophenoxide with Ia.—A solution of thiophenol (11.0 g., 0.10 mole) and sodium methoxide (5.4 g., 0.10 mole) in 50 ml. of methanol was added to a suspension of Ia (17.25 g., 0.050 mole) in 50 ml. of methanol. The solid Ia immediately dissolved, and the solution became warm. Dilute hydrochloric acid (300 ml.) was added slowly, and the mixture extracted with methylene chloride. The methylene chloride was evaporated to give 22.1 g. of crude product, which was redissolved in methylene chloride, extracted with 10% sodium hydroxide solution, dried over magnesium sulfate, and the solvent evaporated to give 10.0 g. (0.046 mole, 92%) of diphenyl disulfide.

The sodium hydroxide washes were acidified with 6 *N* hydrochloric acid and extracted with methylene chloride, which was evaporated to give 11.0 g. (0.0415 mole, 83%) of 2,6-dibromo-4-methylphenol.

Reaction of Ia and Potassium O,O-Diethyl Phosphorodithioate.—A solution of potassium O,O-diethyl phosphorodithioate (6.53 g., 0.029 mole) in 100 ml. of acetone was added to a solution of Ia (10.0 g., 0.029 mole) in 50 ml. of acetone. The yellow cyclohexadienone color immediately disappeared. After stirring for 10 min., the solvent was evaporated. The residue showed no carbonyl absorption in the infrared. It was dissolved in methylene chloride, extracted with dilute sodium hydroxide, and the aqueous layer acidified with hydrochloric acid and extracted with methylene chloride. The methylene chloride layer was dried over magnesium chloride, and evaporated to give 6.65 g. (0.025 mole, 86%) of 2,6-dibromo-4-methylphenol.

Reaction of Dibutyl Sulfide with Ia.—The solid Ia (16.9 g., 0.048 mole) was suspended in 75 ml. of *tert*-butyl alcohol. Dibutyl sulfide (7.0 g., 0.049 mole) was added quickly to the stirred suspension. The solid dissolved almost immediately. After stirring for 10 min., the solution was dissolved in methylene chloride and extracted with 5% potassium hydroxide solution. The methylene chloride layer was washed with water, dried over magnesium sulfate, and evaporated to give 6.9 g. (0.043 mole 89%) of dibutyl sulfoxide, identical in infrared spectrum and v.p.c. retention time with a commercial sample. The potassium hydroxide solution was acidified with concentrated hydrochloric acid, extracted with methylene chloride, and dried over magnesium sulfate. Evaporation left 12.3 g. (0.043 mole, 89%) of 2,6-dibromo-4-methylphenol.

Reaction of Dibutyl Sulfide with 2,4,4,6-Tetrabromocyclohexadien-1-one (Ib).—The reaction was carried out exactly as described for Ia, using 10.5 g. (0.025 mole) of Ib and 3.55 g. (0.025 mole) of dibutyl sulfide, except that ethanol was used as the solvent. A 62% yield of dibutyl sulfoxide and a 91% yield of 2,4,6-tribromophenol were obtained.

---

(16) F. Wessely and F. Sinwel, *Monatsh.*, **81**, 1055 (1950).

The Chemistry of Carbanions. II. The Reaction of Organomagnesium Compounds with α,β-Unsaturated Ketones[1a]

HERBERT O. HOUSE, DANIEL D. TRAFICANTE,[1b] AND ROGER A. EVANS

Department of Chemistry, Massachusetts Institute of Technology, Cambridge 39, Massachusetts

Received July 26, 1962

From product studies of the reactions of *trans*-3-penten-2-one and *trans*-4-phenyl-3-buten-2-one with dimethylmagnesium, diethylmagnesium, and diphenylmagnesium, the following conclusions may be drawn about factors affecting conjugate and normal addition. (1) The presence of magnesium bromide only slightly enhances normal addition. (2) The ratio of conjugate to normal addition is not dependent on the concentration of the dialkylmagnesium, implying that the two reactions are of the same kinetic order. (3) Added cuprous chloride enhances conjugate addition with both dialkylmagnesium and alkylmagnesium bromide. (4) Neither the copper-catalyzed nor the uncatalyzed conjugate addition is diminished by the presence of excess isoprene, indicating that neither conjugate addition process involves free radicals which are reactive toward isoprene.

This paper reports a study (Chart I) of several factors which might be expected to influence the proportions of conjugate addition (or 1,4-addition to form **6**) and normal addition (or 1,2-addition to form **5**) obtained from the reaction of unsaturated ketones **8** with organomagnesium compounds **7**.[2]

The Effect of Magnesium Bromide.—The presence or absence of magnesium bromide in reaction mixtures involving organomagnesium compounds has been reported to affect the course or rate of a variety of reactions. Among these effects are the elimination of epoxide rearrangements in the absence of magnesium bromide,[3] an enhanced rate of reaction of diethylmagnesium with 1-hexyne in the absence of magnesium bromide,[4] an enhanced rate of reaction of dimethylmagnesium with acetone[5] and with benzophenone[6,7] in the absence of magnesium bromide or iodide, a de-

---

(1)(a) This research has been supported in part by the National Science Foundation grant no. G-5107 and in part by grant no. 594A from the Petroleum Research Fund; (b) supported by the U. S. Air Force Academy.

(2) For a discussion of earlier work with leading references, see (a) E. G. Rochow, D. T. Hurd, and R. N. Lewis, "The Chemistry of Organometallic Compounds," John Wiley and Sons, Inc., New York, N. Y., 1957; (b) M. S. Kharasch and O. Reinmuth, "Grignard Reactions of Nonmetallic Substances," Prentice-Hall, Inc., New York, N. Y., 1954.

(3) N. G. Gaylord and E. I. Becker, *Chem. Rev.*, **49**, 413 (1951).

(4) (a) J. H. Wotiz, C. A. Hollingsworth, and R. E. Dessy, *J. Org. Chem.*, **21**, 1063 (1956); (b) J. H. Wotiz, C. A. Hollingsworth, and R. E. Dessy, *J. Am. Chem. Soc.*, **78**, 1221 (1956); (c) R. E. Dessy, J. H. Wotiz, and C. A. Hollingsworth, *ibid.*, **79**, 358 (1957).

(5) J. G. Aston and S. A. Bernhard, *Nature*, **165**, 485 (1950).

(6) N. M. Bikales and E. I. Becker, *Chem. Ind.* (London), 1831 (1961).

(7) (a) M. Anteunis, *J. Org. Chem.*, **26**, 4214 (1961); (b) M. Anteunis, *ibid.*, **27**, 596 (1962).