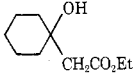
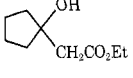
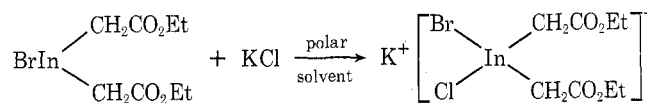


Table III  
Summary of Reformatsky Reaction of Carbonyl Compounds with Activated Indium and Ethyl Bromoacetate<sup>a</sup>

Carbonyl compd	Product	Registry no.	Solvent	Reaction temp, °C	% yield <sup>b</sup>
Cyclohexanone		5326-50-1	Xylene	55	100
Cyclopentanone		3197-76-0	Xylene	55	80
Benzaldehyde	C <sub>6</sub> H <sub>5</sub> CH(OH)CH <sub>2</sub> CO <sub>2</sub> Et	5764-85-2	Xylene	55	83-100
<i>p</i> -Methylacetophenone	CH <sub>3</sub> C <sub>6</sub> H <sub>4</sub> C(OH)(CH <sub>3</sub> )CH <sub>2</sub> CO <sub>2</sub> Et	55319-45-4	Et <sub>2</sub> O	34	59

<sup>a</sup> All reactions were carried out for 2 hr. <sup>b</sup> Based upon GLC analysis using internal standard, BrCH<sub>2</sub>CO<sub>2</sub>Et/2 = 100%. <sup>c</sup> The factor of 1/2 is necessary because only one -CH<sub>2</sub>CO<sub>2</sub>Et group of BrIn(CH<sub>2</sub>CO<sub>2</sub>Et)<sub>2</sub> adds to a ketone or aldehyde.

lide ratio was 0.85:1.00:2.02 and it contained 25.6% of In. This fits the structure of the ate complex of (EtOCO-CH<sub>2</sub>)<sub>2</sub>InBr with KCl. Thus it appears that the composition



of this Reformatsky reagent is quite solvent dependent, with the ate complex being favored in polar solvents. We examined the effect of the solvent on the yield of the  $\beta$ -hydroxy ester and the results are summarized in Table I. It is readily apparent that the reactions in polar solvents gave lower yields and more side products. We attribute these results to the formation of the ate complex in polar solvents.

In order to obtain good yields of  $\beta$ -hydroxy esters, several reaction conditions must be carefully controlled. In the preparation of the activated indium it is very important that the molar ratio of InCl<sub>3</sub> to K be exactly 1:3. If there is an excess of either InCl<sub>3</sub> or K, side reaction products become considerable. The ratio of the carbonyl compound to the  $\alpha$ -bromoacetate is also very critical. In order to obtain high yields, a onefold excess of the carbonyl compound is necessary; the excess carbonyl compound can be recovered later. The reason for the necessity of the excess carbonyl compound is not readily obvious. Some of the results with varying ratios of bromoacetate to ketone are summarized in Table II.

Finally, the results of reactions of a variety of carbonyl compounds with the activated indium and ethyl  $\alpha$ -bromoacetate are summarized in Table III. In general, the yields of  $\beta$ -hydroxy esters are good with ketones and also with benzaldehyde in xylene and diethyl ether. However, alkyl aldehydes give relatively low yields.

### Experimental Section

**Materials.** Cyclohexanone, cyclopentanone, benzaldehyde, *p*-methylacetophenone, ethyl bromoacetate, and ethyl chloroacetate were obtained from commercial sources. They were used without further purification. Xylene (ortho, 99%) was obtained from Aldrich and distilled over NaAlH<sub>4</sub>. Diethyl ether (Fisher Anhydrous) and THF (MCB) were distilled over LiAlH<sub>4</sub> under argon. Commercial indium (325 mesh, 99.9%) and anhydrous indium trichloride were obtained from Alfa. Potassium (Baker purified) was cleaned under heptane prior to use. Activated indium metal was prepared by reducing indium trichloride with potassium in xylene by refluxing for 4-6 hr under an argon atmosphere.

**Reactions Using Activated Indium.** The following procedure for the conversion of cyclohexanone to ethyl (1-hydroxycyclohexyl)acetate is representative. Activated indium metal (10 mmol) was prepared from the reduction of InCl<sub>3</sub> (2.21 g, 10 mmol) and K (1.17 g, 30 g-atoms) in 25 ml of xylene in a 100-ml round-bottom flask with a side arm equipped with a septum cap under an argon atmosphere. After refluxing for 4.5 hr the mixtures were cooled

down to 2° with ice-water, 1.0 g of biphenyl was added as an internal standard, and then two loaded syringes with cyclohexanone (0.93 g, 9.5 mmol) and ethyl bromoacetate (1.5 g, 9.5 mmol) were inserted into the flask via a septum cap. Both components were added simultaneously and stirred at 2° for 10 min; then the mixtures were heated to 55°. One 2-ml sample was withdrawn periodically and hydrolyzed with 2 *N* HCl solution. The organic layer was subjected to GLC. GLC analyses were carried out with an HP Model 5750 research gas chromatograph equipped with 6 ft × 0.125 in. stainless steel columns packed with 10% SE-30 on Chromosorb W. The product was identified by comparing GLC retention time with that of the authentic sample obtained from the regular zinc Reformatsky reaction.

**Acknowledgment.** Support of this research by the U.S. Army Research Office is gratefully acknowledged.

**Registry No.**—Cyclohexanone, 108-94-1; cyclopentanone, 120-92-3; benzaldehyde, 100-52-7; *p*-methylacetophenone, 122-00-9; ethyl bromoacetate, 105-36-2; ethyl chloroacetate, 105-39-5; indium, 7440-74-6; InCl<sub>3</sub>, 10025-82-8; K, 7440-09-7.

### References and Notes

- (1) For Part VIII of this series see R. D. Rieke, K. Öfele, and E. O. Fischer, *J. Organomet. Chem.*, **76**, C19 (1974).
- (2) Alfred P. Sloan Research Fellow, 1973-1975. Author to whom correspondence should be sent.
- (3) L. M. Dennis, R. W. Work, and E. G. Rochow, *J. Am. Chem. Soc.*, **56**, 1047 (1934).
- (4) H. Gilman and R. G. Jones, *J. Am. Chem. Soc.*, **62**, 2353 (1940).
- (5) H. D. Visser and J. P. Oliver, *J. Organomet. Chem.*, **40**, 7 (1972).
- (6) M. J. S. Gynane, L. G. Waterworth, and I. J. Worrall, *J. Organomet. Chem.*, **40**, C9 (1972).
- (7) R. D. Rieke, *Top. Curr. Chem.*, submitted for publication.
- (8) L.-C. Chao and R. D. Rieke, *Synth. React. Inorg. Metal-Org. Chem.*, **4**, 373 (1974).
- (9) L.-C. Chao and R. D. Rieke, *J. Organomet. Chem.*, **67**, C64 (1974).
- (10) J. F. Ruppert and J. D. White, *J. Org. Chem.*, **39**, 269 (1974).
- (11) M. W. Rathke and A. Lindert, *J. Org. Chem.*, **35**, 3966 (1970).

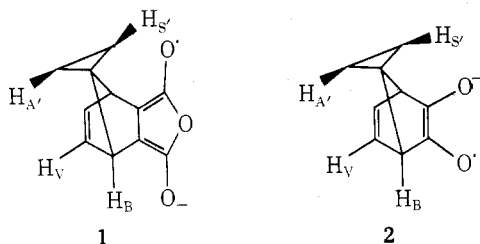
### Long Range Electron Paramagnetic Resonance Coupling Interactions in Spiro Derivatives of Bicyclo[2.2.1]heptyl Semiquinone

Daniel Kosman and Leon M. Stock\*

Department of Chemistry, University of Chicago,  
Chicago, Illinois 60637

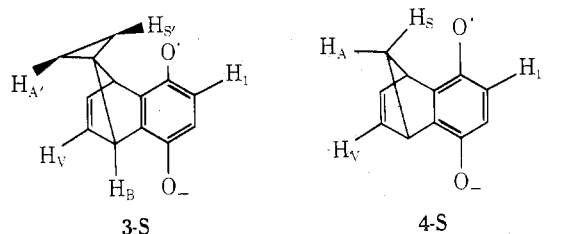
Received February 4, 1975

Nelsen,<sup>1</sup> Blankespoor,<sup>2</sup> and Russell<sup>3</sup> and their associates have investigated long range  $\delta$  coupling constants in the semifuraquinone (1) and semidione (2) series. The observations for 1 and 2 illustrate that the interactions between

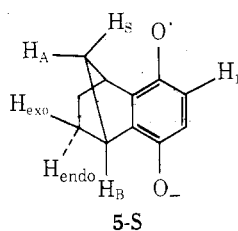


$$\begin{array}{ll}
 a = 1.07 \text{ (2 H), } H_{A'} & a = 0.95 \text{ (2 H), } H_B \\
 0.81 \text{ (2 H), } H_V & 0.68 \text{ (2 H), } H_V \\
 0.52 \text{ (2 H), } H_{S'} \text{ or } H_B & 0.20 \text{ (2 H), } H_{A'} \\
 0.46 \text{ (2 H), } H_B \text{ or } H_{S'} &
 \end{array}$$

the  $\delta$  hydrogen atoms and the spin label can, indeed, be large as we previously noted for the related semiquinone 3-S.<sup>4,5</sup> Comparison of these values with the data for 4-S and 5-S indicate that the spin population at the anti' and syn' hydrogen atoms of the cyclopropane ring is quite large. This finding prompted us to examine the less strained saturated semiquinone, 6-S, and the related cyclopentane derivatives, 7-S and 8-S, in which the  $\delta$  hydrogen atoms occur



$$\begin{array}{ll}
 a = 2.40 \text{ (2 H), } H_1 & a = 2.36 \text{ G (2 H), } H_1 \\
 0.47 \text{ (2 H), } H_V & 0.80 \text{ G (1 H), } H_A \\
 0.38 \text{ (2 H), } H_{A'} & 0.40 \text{ G (3 H), } H_V, H_S \\
 0.18 \text{ (2 H), } H_{S'} \text{ or } H_B & \\
 0.10 \text{ (2 H), } H_B \text{ or } H_{S'} &
 \end{array}$$

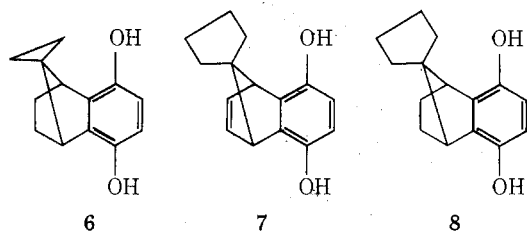


$$\begin{array}{l}
 a = 2.50 \text{ G (2 H), } H_1 \\
 0.70 \text{ G (3 H), } H_{\text{exo}}, H_A
 \end{array}$$

py essentially the same positions in space in molecules with more normal carbon-carbon bond hybridization.

### Results

Spiro[2.4]hepta-2,4-diene and spiro[4.4]nona-2,4-diene were prepared from cyclopentadiene and the appropriate



dibromoalkane using sodium hydride in diglyme. This procedure is more convenient than methods using sodamide and ammonia.<sup>6</sup> Adduct formation with benzoquinone, tautomerization to the hydroquinone, and reduction of the isolated double bond proceeded smoothly.<sup>4</sup>

Semiquinones 3-S, 6-S, and 7-S were generated by air oxidation of the hydroquinone ( $10^{-3}$  M) in acetonitrile containing sodium hydroxide. Semiquinone 8-S ( $10^{-3}$  M) was prepared from the corresponding diacetate in dimethyl sulfoxide containing potassium *tert*-butoxide. Experience indicates that the important features of the spectra are unaltered by this variation in the procedure.<sup>4</sup> The coupling constants are presented in Table I.

**Table I**  
Coupling Constants for Semiquinones<sup>a</sup>

Nucleus	Coupling constant, G			
	3-S	6-S	7-S	8-S
H <sub>1</sub>	2.40	2.55	2.40	2.60
H <sub>V</sub>	0.47		0.40	
H <sub>EXO</sub>		0.81		0.85
H <sub>ENDO</sub>		0.10		<i>b</i>
H <sub>B</sub>	0.10 (0.18)	<i>b</i> (0.10)	<i>b</i> (0.08)	<i>b</i>
H <sub>A'</sub>	0.38	0.23	0.40	0.25
H <sub>S'</sub>	0.18 (0.10)	0.10 ( <i>b</i> )	0.08 ( <i>b</i> )	<i>b</i>

<sup>a</sup> Alternative assignments, where appropriate, are presented in parentheses. <sup>b</sup> Undetectably small.

### Discussion

The constants for the aryl, vinyl, and exo hydrogen atoms of 3-S, and 6-S-8-S can be assigned on the basis of prior data for the many derivatives of 4-S and 5-S.<sup>4</sup> For 8-S, there is only one additional coupling constant which is reasonably assigned to the anti' hydrogen atoms of the cyclopentane ring.<sup>7a</sup> For 7-S there are two additional constants which must be assigned. We reported previously that the introduction of unsaturation increases the magnitude of the anti and syn coupling constants.<sup>4</sup> Consequently, the larger constant may be assigned to H<sub>A'</sub> and the smaller constant to H<sub>S'</sub>. Prior work on both the semiquinones and semifuraquinones indicates that the bridgehead hydrogen atoms exhibit the smallest coupling constants.<sup>1,4</sup> However, an alternate, less likely assignment for 7-S is shown in Table I.

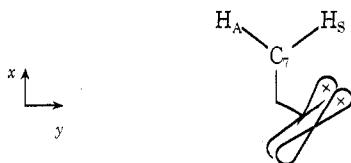
Semiquinones 6-S and 8-S exhibit essentially the same spectrum except that four additional hydrogen atoms of 6-S exhibit small coupling constants. It is likely that the bridgehead hydrogen atoms remain uncoupled. The alternative assignment is, however, noted in Table I. All the hydrogen atoms of 3-S are coupled. The larger constants are assigned to the vinyl and anti' hydrogen atoms with the smaller pair assigned to the bridgehead and syn' groups.

The results (Table I) reveal that spin density appears at remote sites in 3-S and 6-S-8-S. The coupling constants for the vinyl and exo hydrogen atoms in these four radicals are comparable to the constants for 4-S and 5-S. The coupling constants of the syn' and anti' methylene groups of the cyclopropane and cyclopentane fragments are quite large. These constants are nearly equal for the heptadienes, 3-S and 7-S, with  $a_{H_{A'}} = 0.38$  and 0.40 G, respectively, and for the heptenes, 6-S and 8-S, with  $a_{H_{A'}} = 0.25$  and 0.23 G, respectively.<sup>7b</sup> Thus, the additional strain in the cyclopropane derivatives does not have an important impact on the magnitude of the coupling interaction. The near equality of the constants suggests that simple geometric relationships rather than bond hybridization factors play a dominant role in the determination of spin density at the  $\delta$  hydrogen atoms. The constants for the anti' hydrogen atoms of 3-S and 7-S are about 50% of the value of  $a_{H_A}$  for 4-S. Similar results have been reported for the semifuraquinone.<sup>1</sup> On

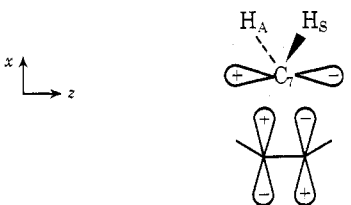
the other hand, the constant for the anti' hydrogen atom of the semidione **2** is only about 2% of the value of  $a_{H_A}$  in bicyclo[2.2.1]hepta-5-ene-2,3-semidione.<sup>2,3</sup>

Several interactions require consideration in the interpretation of these constants. Spin density is distributed in molecules by direct and indirect interactions involving the delocalization and polarization of electrons. The spin density measured at a particular nucleus may, therefore, result from four distinct contributions. Indeed, only relatively advanced theories such as the INDO model or configuration interaction formulations which focus on spin polarization can adequately estimate spin distributions.<sup>8,9</sup> Nevertheless, simple concepts such as hyperconjugation, homohyperconjugation, the W plan arrangement, and the symmetry properties of the orbitals of the spin label have proved valuable for the qualitative discussion of the factors governing long range coupling constants.<sup>1-4</sup>

In the absence of confident information concerning the signs of the long range coupling constants, all explanations are somewhat speculative. However, the INDO model can be used to guide these interpretations. Homohyperconjugation, the INDO model, and a CI approach have been employed to account for the stereospecific coupling interaction of the  $H_A$  nucleus in bicyclo[2.2.1]heptane-2,3-semidione.<sup>3,9,10</sup> Because the highest occupied molecular orbital of the semidione is symmetric, the orbitals of the spin label can mix with the  $s$ ,  $p_x$ , and  $p_y$  orbitals of the  $C_7$  group directly to delocalize the spin density and place large, apparently positive, spin at  $H_A$ . This explanation is not applica-



ble for spin labels such as the semiquinone or semifuraquinone with antisymmetric highest occupied molecular orbitals, in these cases the orbital of the spin label can only mix with the  $p_z$  orbital to place spin density in a  $2p$  orbital at  $C_7$ . The syn and anti protons then couple via an indirect



spin polarization interaction. The constants for these nuclei should be negative as predicted by the INDO model.<sup>3</sup> Nelsen, Travecedo, and Seppanen adopted this viewpoint in their analysis of the coupling interactions in bicyclo[2.2.1]hept-5-ene-2,3-semifuraquinone.<sup>1</sup>

These qualitative ideas can account for the coupling behavior of the syn' and anti' methylene groups in the spirocyclopropyl and spirocyclopentyl derivatives of the semidione, semifuraquinone, and semiquinone. For the semiquinones and the semifuraquinones, spin density may be propagated to the methylene groups, in part, through an interaction between the spin in the  $p_z$  orbital centered at  $C_7$  and the C-H bonding orbitals. Consequently, the spin populations at  $H_A$ ' are quite large. In this case, a negative constant for the methylene groups is expected. For the semidione **2**, there is no spin in an orbital with a geometry favorable for the coupling of the syn' and anti' methylene groups; only a rather small coupling is observed. Thus, this model adequately portrays the principal features of the

spectra. We note, however, that the spin density at these remote nuclei are, in fact, determined by the spin populations in many nearby orbitals and that more subtle mechanisms must also play a role.

### Experimental Section

**3',6'-Dihydroxybenzobicyclo[2.2.1]hepta-2,5-diene-7-spirocyclopropane (3).** Spiro[2.4]hepta-2,4-diene was prepared from cyclopentadiene and 1,2-dibromoethane. Sodium hydride (48%, 34.0 g, 0.67 mol) was suspended in diglyme (175 ml, freshly distilled from lithium aluminum hydride) in a flask equipped with a mechanical stirrer, dropping funnel, and a condenser fitted with a nitrogen inlet tube. This flask was cooled to 0° and cyclopentadiene (22.0 g, 0.33 mol) in diglyme (25 ml) was added slowly with very vigorous stirring. After 0.5 hr, 1,2-dibromoethane (63.0 g, 0.34 mol) in diglyme (25 ml) was added over 0.5 hr. Additional solvent (50 ml) was added. After 3 hr, water (25 ml) was added cautiously, then pentane (100 ml), and the entire mixture was poured into ice-water (500 ml). The layers were separated, the aqueous phase was extracted with pentane (3 × 50 ml), and the combined organic layers were washed with cold, saturated sodium chloride solution (3 × 50 ml). After drying over sodium sulfate, the pentane was removed by distillation, then the product was distilled at reduced pressure. The first fraction [bp 40–44° (75 mm), 4.95 g] was a 1:1 mixture of the product and diglyme; the second fraction [bp 53° (75 mm), 9.4 g] contained 95% spiro[2.4]hepta-2,4-diene. The total yield was 11.8 g (38% based on cyclopentadiene).

Spiro[2.4]hepta-2,4-diene (11.8 g, 0.13 mol) in methanol (10 ml) was added to benzoquinone (13.8 g, 0.13 mol) suspended in methanol (50 ml) in a flask cooled in an ice-water bath. The bath was removed and the solution was stirred magnetically for 1 hr. The product was filtered cold, washed with cold methanol, and dried in vacuo. This adduct (21.0 g, mp 109.5–110.0°) was recrystallized from methanol. The adduct then was converted to the diacetate (mp 96.5–96.8° from methanol) by base-catalyzed tautomerization and acetylation as described previously.<sup>4</sup> The diacetate was hydrolyzed as described previously to yield 3',6'-dihydroxybenzobicyclo[2.2.1]hepta-2,5-diene-7-spirocyclopropane (**3**) (mp 171.0–172.5° from benzene).

Anal. Calcd for  $C_{13}H_{12}O_2$ : C, 78.00; H, 6.00. Found: C, 77.94; H, 6.08.

**3',6'-Dihydroxybenzobicyclo[2.2.1]hept-2-ene-7-spirocyclopropane (6).** This compound (mp 193.0–194.0° from benzene) was prepared from **3** via platinum-catalyzed low-pressure hydrogenation.

Anal. Calcd for  $C_{13}H_{14}O_2$ : C, 77.25; H, 6.94. Found: C, 77.18; H, 6.99.

**3',6'-Dihydroxybenzobicyclo[2.2.1]hepta-2,5-diene-7-spirocyclopentane (7).** Spiro[4.4]nona-2,4-diene, bp 48° (15 mm), was prepared from cyclopentadiene and 1,4-dibromobutane in 22% yield by the method used for the synthesis of spiro[2.4]hepta-2,4-diene.

The adduct (mp 98.0–98.5° from methanol) of spiro[4.4]nona-2,4-diene and benzoquinone was prepared in 89% yield as described above. The diacetate (mp 72.0–73.0° after sublimation) was prepared as described previously and hydrolyzed to 3',6'-dihydroxybenzobicyclo[2.2.1]hepta-2,5-diene-7-spirocyclopentane (**7**) (mp 167.0–168.0° from benzene) under acidic conditions.

Anal. Calcd for  $C_{15}H_{16}O_2$ : C, 79.00; H, 7.02. Found: C, 79.11; H, 7.07.

**3',6'-Diacetoxybenzobicyclo[2.2.1]hept-2-ene-7-spiropentane (8-D).** The diacetate prepared in the synthesis of **7** was hydrogenated at low pressure with platinum to yield 3',6'-diacetoxybenzobicyclo[2.2.1]hept-2-ene-7-spiropentane (**8-D**) (mp 97.5–99.0° after sublimation).

**Spectroscopic Results.** The semiquinone derived from **8** was prepared by the hydrolysis of the related diacetate ( $10^{-3}$  M) in dimethyl sulfoxide containing potassium *tert*-butoxide. The other semiquinones were prepared by air oxidation of the hydroquinones ( $10^{-3}$  M) in acetonitrile. All the spectra were recorded on a Varian E3 spectrometer. The field sweep was calibrated by the study of perylene cation radical. All the spectra were simulated with a Jeolco JRA5 system.

**Acknowledgment.** Acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for partial support of this research and to the Block Fund of the University of Chicago.

**Registry No.**—**3**, 55373-45-0; **3-D**, 55373-46-1; **3-S**, 55428-86-9; **6**, 55373-47-2; **6-S**, 55373-48-3; **7**, 55373-49-4; **7-D**, 55373-50-7; **7-S**, 55373-51-8; **8**, 55373-52-9; **8-D**, 55373-53-0; **8-S**, 55373-54-1; spiro[2.4]hepta-2,4-diene, 765-46-8; cyclopentadiene, 542-92-7; 1,2-dibromoethane, 106-93-4; benzoquinone, 106-51-4; 3',6'-dioxobenzobicyclo[2.2.1]heptadiene-7-spirocyclopropane, 55373-55-2; spiro[4.4]nona-2,4-diene, 766-29-0; 1,4-dibromobutane, 110-52-1; 3',6'-dioxobenzobicyclo[2.2.1]hepta-2,5-diene-7-spirocyclopentane, 55373-56-3.

### References and Notes

- (1) S. F. Nelsen, E. F. Travecedo, and E. D. Seppanen, *J. Am. Chem. Soc.*, **93**, 2913 (1971).
- (2) R. L. Blankespoor, *J. Am. Chem. Soc.*, **96**, 6196 (1974).
- (3) G. A. Russell, G. W. Holland, K. Chang, R. G. Keske, J. Mattox, C. S. C. Chung, K. Stanley, K. Schmitt, R. Blankespoor, and Y. Kosugi, *J. Am. Chem. Soc.*, **96**, 7237 (1974).
- (4) D. Kosman and L. M. Stock, *J. Am. Chem. Soc.*, **91**, 2011 (1969).
- (5) A numeral identifies the hydroquinone, a D indicates the diacetate, and an S indicates the semiquinone.
- (6) C. F. Wilcox, Jr., and R. R. Craig, *J. Am. Chem. Soc.*, **83**, 3866 (1961).
- (7) (a) Nelsen and his associates showed that the anti' protons were coupled to a greater extent than the syn' protons in **1** by the study of a methylated derivative.<sup>1</sup> (b) Nelsen and his associates found a small decrease in  $a_{\text{H}_A}$  when a cyclopentane ring replaces the cyclopropane ring in **1** compared to the tiny increase in  $a_{\text{H}_A}$  for **3-S** and **7-S**. We thank Professor Nelsen for calling this point to our attention.
- (8) J. A. Pople, D. L. Beveridge, and P. A. Dobosh, *J. Am. Chem. Soc.*, **90**, 4201 (1968).
- (9) Y. Ellinger, A. Rassat, R. Subra, and G. Berthier, *J. Am. Chem. Soc.*, **95**, 2372 (1973).
- (10) G. R. Underwood and V. L. Vogel, *J. Am. Chem. Soc.*, **93**, 1058 (1971).