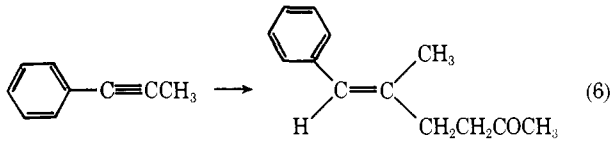

(6)

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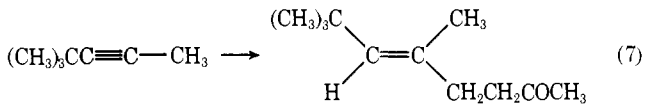

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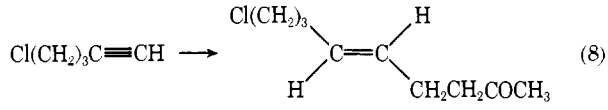

(8)

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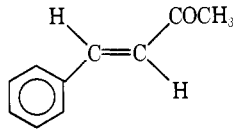
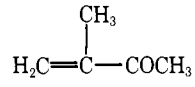
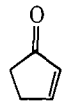
desired products in the indicated yields; the transoid ketones, **13** and **14**, gave complex mixtures in which we failed to find the desired products.



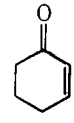
11, 90%



12, 50%

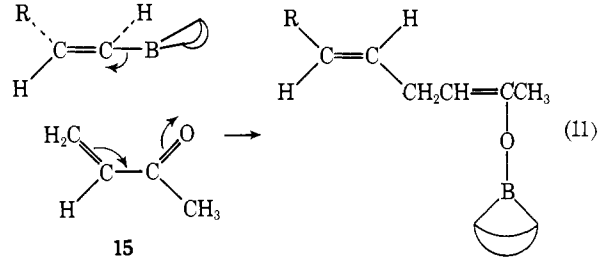


13, 0%



14, 0%

These results are consistent with a process (eq 11) which proceeds via a cyclic species (**15**), transferring the vinyl group from boron to carbon with retention of its stereochemistry, giving the intermediate **16**, which is hydrolyzed to the desired product (eq 1).



(11)

15 16

The reaction evidently involves a regio- and stereospecific replacement of boron by carbon. Thus, the hydroboration of a terminal acetylene provides the pure trans alkenyl derivative.[7] In each case only a single product was indicated by the NMR and GC examination. All of the product obtained from the reaction of *trans*-1-alkenyl-9-BBN derivatives with methyl vinyl ketone exhibited a strong band at ~970 cm^{-1} in their infrared spectra, indicating a trans disubstituted olefinic linkage.[8] We undertook to confirm the conclusion that these reactions proceed with retention by reducing[9] **4** to 5-decene. In synthetic mixtures, we could detect 1% *cis*-5-decene in 99% trans. However, in the product from **4** there was no measurable trans detected.

The following procedure for the preparation of 7,7-dimethyl-*trans*-5-octen-2-one is representative. To an oven-dried nitrogen-flushed 500-ml flask equipped with a reflux condenser and magnetic stirring bar was added 208 ml of 0.48 M 9-BBN[10] (100 mmol) in THF. The solution was cooled in an ice-water bath, and 9.1 g (110 mmol) of 3,3-dimethyl-1-butyne was added over 5 min. The mixture was then stirred overnight at room temperature to ensure complete hydroboration. Methyl vinyl ketone (7.7 g, 110 mmol) was added, and the solution was heated under reflux for 16 h.[11] After cooling to room temperature, the residual organoborane was oxidized by adding 3 N sodium hydroxide (40 ml), followed by the slow addition of 40 ml of 30% hydrogen peroxide (*Caution:* exothermic). The reaction mixture was maintained at 50 °C for 1 h to ensure complete oxidation. The aqueous layer was saturated with anhydrous potassium carbonate, separated, and extracted with hexane. After drying over anhydrous magnesium sulfate, the combined organic layer was distilled to provide 13.1 g (85%) of 7,7-dimethyl-*trans*-5-octen-2-one: bp 80–82 °C (12 mm); n^{20}_D 1.4355; semicarbazone mp 132.5–133.5 °C; IR (neat) 1720, 975 cm^{-1}; ^1H NMR (CCl_4, Me_4Si) δ 0.95 (s, 9 H), 2.05 (s, 3 H), 2.2–2.4 (m, 4 H), 5.4 (m, 2 H).

It is evident that this procedure makes it practical to achieve the conjugate addition of vinyl groups stereospecifically to methyl vinyl ketone and related derivatives. Perhaps even more important is the evident opening up of a new reaction path for the utilization of organoborane derivatives with their unique and valuable characteristics[7] for synthetic applications.

Acknowledgments. The authors wish to thank Dr. M. M. Midland and Dr. S. Krishnamurthy for advice concerning the stereochemical determination.

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(10) Solid 9-BBN and solutions of 9-BBN in THF are available from the Aldrich Chemical Co., Milwaukee, Wis.
(11) In most cases, the maximum yield was reached after 3–4 h, but it was often convenient to allow the reaction mixture to reflux overnight.
(12) For example, the addition of small amounts of oxygen, which catalyzes the conjugate addition of trialkylboranes to α,β-unsaturated ketones,[5] did not induce a reaction between *trans*-1-hexenyldiphenylborane and methyl vinyl ketone. Similarly, catalytic quantities of oxygen did not result in any observable change in the rate of reaction of *B-trans*-1-hexenyl-9-BBN with methyl vinyl ketone. Nor did the presence of small amounts of iodine, a known inhibitor for free radical reactions of organoboranes,[13] have any effect.
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(14) Graduate research assistant on grants provided by the National Science Foundation (GP-27742X) and by G. D. Searle and Company, Chicago, Ill.

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Hydride Transfer Reactions. Oxidation of *N*-Methylacridan by 1,4-Benzoquinone and Related π Acceptors

Sir:

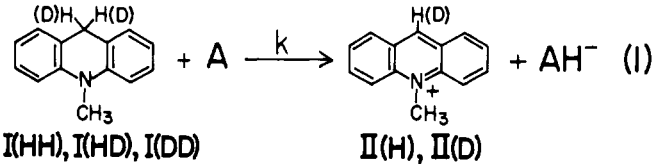
Oxidations of dihydropyridines and related compounds by hydride acceptors are of interest as models for biological oxidation–reduction reactions involving the pyridine nucleotide coenzymes,[1] and as reactions of π donors with π acceptors.[2]

Table I. Kinetics of Oxidation of *N*-Methylacridan (I)[a]

Acceptor	[Acceptor], M	k, M^{-1} s^{-1} [b] I(HH)	I(HD)	I(DD)
1,4-Benzoquinone (BQ)[c]	9.87×10^{-2}	1.42×10^{-2}	7.40×10^{-3}	1.48×10^{-3}
1,4-Benzoquinone (BQ)[d]	5.00×10^{-1}	5.79×10^{-4}	2.96×10^{-4}	4.11×10^{-5}
Tetracyanoquinodimethane (TCNQ)	1.54×10^{-2}	2.32×10^{-1}	1.18×10^{-1}	3.21×10^{-2}
Chloranil (CA)	4.18×10^{-3}	1.17×10	5.91	1.34
2,3-Dicyano-1,4-benzoquinone (DCBQ)	2.02×10^{-3}	8.67×10^{3}	4.80×10^{3}	1.49×10^{3}

[a] Temperature 25.0 ± 0.1 °C, solvent acetonitrile (AN) except where noted, and concentration of I 0.8–2.0 × 10^{-4} M. [b] Pseudo-first-order rate constants ÷ stoichiometric acceptor concentrations. Rate constants reproducible to ±1% with BQ, TCNQ, and CA, ±3% with DCBQ. [c] Solvent 60/40 (v/v) AN/H_2O–0.01 M acetic acid. [d] Solvent AN–0.01 M acetic acid.

Although generally viewed as one-step hydride transfers, several mechanisms involving sequential transfer of one or two electrons and a hydrogen atom or proton are possible in theory, and evidence for free radical intermediates has been reported in isolated instances.[3] Recently, evidence has been reported for one or more intermediates in the oxidation of N-substituted-1,4-dihydronicotinamides by trifluoroacetophenone[4] and *N*-methylacridinium ion.[5] We have measured kinetic isotope effects and isotope partitioning ratios (ipr's) in the reaction (eq 1) of *N*-methylacridan (I) with a series of strong π (and hydride) acceptors (A) covering a 10^7-fold range of reactivity. The strong π acceptors, the lower ionization potential of I[6] and the smaller gain in resonance energy accompanying aromatization[7] (compared to the dihydronicotinamides) should all favor a radical ion intermediate. The results (Tables I and II) are completely consistent with a one-step hydride transfer mechanism.



I(HH), I(HD), I(DD) II(H), II(D)

The stoichiometry of the reaction is as represented by eq 1 for BQ and CA; with TCNQ and DCBQ the reduction product is the radical ion ($A^{\cdot -}$) plus fully reduced acceptor (AH_2) (0.5 mol), presumably formed by reaction of initially formed AH^- with A.[8] The progress of the reaction was followed spectrophotometrically utilizing the acridinium ion absorption at 359 nm (BQ) or 420 nm (CA, DCBQ) or that of the radical anion (TCNQ, 680 nm), the DCBQ reaction by stopped-flow spectrophotometry. The kinetics are strictly first order in each reactant, except with BQ in AN, where concentrations of 0.50 M were necessitated by the photochemical instability and low reactivity of the acceptor. Measurements in AN/H_2O mixtures[9] indicate that because of complexation between I and BQ, the calculated second-order rate constant at 0.5 M BQ may be as much as 15% smaller than the true second-order rate constant. However, barring extraordinarily large secondary isotope effects on the complexation constant, such corrections will have no measurable effect on the kinetic isotope effects.

A one-step hydride-transfer mechanism leads to the relationships summarized in Scheme I. The primary isotope effect, p (k_H/k_D or k_H'/k_D'), and the secondary isotope effect, s (k_H/k_H' or k_D/k_D'), calculated from the kinetic data using eq 2 and 3, are listed in table II.

$$\frac{k(\mathrm{HH})}{k(\mathrm{DD})} = ps \tag{2}$$

$$\frac{k(\mathrm{HD})}{k(\mathrm{DD})} = \frac{p+s}{2} \tag{3}$$

The ipr, the ratio of II(D) to II(H) formed from I(HD), is given by k_H'/k_D, or p/s. Values of the ipr, determined for three

Table II. Kinetic Isotope Effects and Isotope Partitioning Ratios[a]

Acceptor	Kinetic isotope effects[b] p	s	p/s	ipr[c]
BQ[d]	8.95 ± 0.16	1.08 ± 0.02	8.3 ± 0.2	8.1 ± 1.4
BQ[e]	13.3 ± 0.2	1.06 ± 0.02	12.6 ± 0.3	
TCNQ	6.20 ± 0.17	1.16 ± 0.04	5.3 ± 0.2	
CA	7.66 ± 0.27	1.14 ± 0.05	6.7 ± 0.4	6.2 ± 0.6
DCBQ	5.37 ± 0.35	1.09 ± 0.08	4.9 ± 0.5	4.7 ± 0.1

[a] Temperature 25.0 ± 1 °C and solvent AN except where noted. [b] Calculated using eq 2 and 3. Errors based on ±3% uncertainty in DCBQ rate constants and ±1% in the others. [c] Ratio II(D)/II(H) by mass spectral analysis. [d] Solvent 60/40 (v/v) AN/H_2O–0.01 M acetic acid. [e] Solvent AN–0.01 M acetic acid.

Scheme I

$$\mathrm{I(HH)} \xrightarrow{2k_H} \mathrm{II(H)};\ k(\mathrm{HH}) = 2k_H$$

$$\mathrm{I(HD)} \begin{cases} \xrightarrow{k_H'} \mathrm{II(D)} \\ \xrightarrow{k_D} \mathrm{II(H)} \end{cases};\ k(\mathrm{HD}) = k_H' + k_D$$

$$\mathrm{I(DD)} \xrightarrow{2k_D'} \mathrm{II(DD)};\ k = 2k_D'$$

of the acceptors by mass spectral analysis of isolated acridinium chloride,[10] are listed for comparison with the kinetically determined values of p/s.

The normal primary and secondary isotope effects, and the agreement between the p/s ratios determined kinetically and by product analysis are consistent with a mechanism involving rate-determining hydride transfer, or with a mechanism involving rapid electron transfer followed by slow hydrogen atom transfer. I is approximately 10^3 times less reactive than *N*-propyl-1,4-dihydronicotinamide in reaction with BQ in AN.[9] This and the large primary isotope effects strongly indicate a transition state intermediate in structure between I and II but are inconsistent with a transition state resembling the donor radical cation. Further investigations aimed at an understanding of the strikingly different behavior of I and the *N*-alkyldihydronicotinamides are in progress.

Acknowledgment. This work was supported by the National Research Council of Canada.

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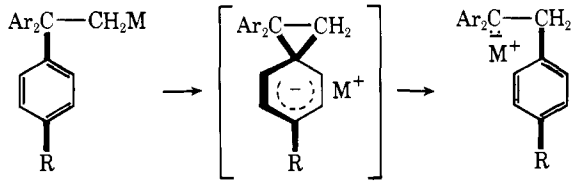
Carbanions. 18. Spiro Anions from Reactions of 2- and 3-*p*-Biphenylylalkyl Chlorides with Cesium–Potassium–Sodium Alloy

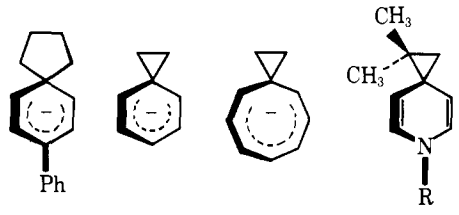
Sir:

Spiro anions (**1**) have long been suggested as intermediates or transition states[1] in [1,2] migrations of aryl groups in or-



1

ganoalkali compounds. That this interpretation is reasonable was indicated by the preparation[2,3] of the stable anion **2** from reaction of 4-chloro-1-*p*-biphenylylbutane with alkali metals. Staley and co-workers[4] have reported that attempts to generate the spiro anion **3** by reactions of spiro[2.5]octa-4,7-diene with potassium amide in liquid ammonia at temperatures as low as −65 °C or with *n*-butyllithium in tetrahydrofuran–hexane at room temperature resulted only in products in which the cyclopropane ring was opened. In contrast the related species **4** could be prepared[4] in liquid ammonia and was stable in this solvent at −30 °C. This comparative stability is attributable to the fact that the product of cyclopropyl ring opening of **4** would be a nonaromatic cyclooctatetraene derivative, whereas that from **3** is aromatic. These observations leave unanswered the question of whether **1** and **3** more nearly represent transition states or reaction intermediates. That various nitrogen analogues **5** of the carbanion **3** have been synthesized[5] lends



2 **3** **4** **5**

encouragement that some derivatives of **3** may be stable. We wish to report preparation and characterization by carbonation of the spiro anions **6** and **7**.

Reaction of 2.5 g of 3-chloro-1-*p*-biphenylylpropane (mp 32–33 °C)[6a] with 7.7 g of Cs–K–Na alloy of eutectic composition[6b] in tetrahydrofuran (THF) at −75 °C, according to a general procedure already described,[2b] gave a red solution which, as soon as it turned green-black, was carbonated (total

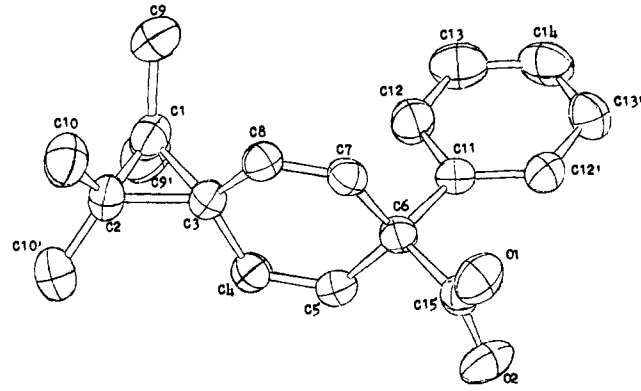
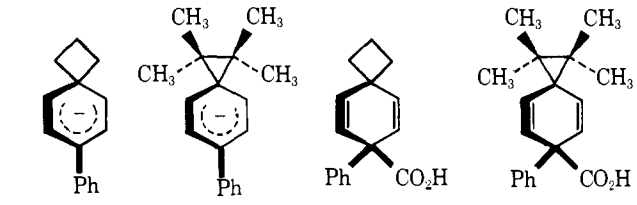


Figure 1. A perspective view of the molecular structure of the acid **11**.



6 **7** **8** **11**

reaction time of 1 min). The usual workup gave, according to a quantitative GLC analysis, 36% yield (based on starting chloride) of **8**, 14% of *p*-biphenylylacetic acid, 3% of 2-*p*-biphenylylbutanoic acid, and 6% of 4-*p*-biphenylylbutanoic acid. The identity of **8**, mp 130.5–131.5 °C, as 7-phenylspiro[3.5]-nona-5,8-diene-7-carboxylic acid was established after separation by liquid chromatography on silica gel (elution with mixture of ether, cyclohexane, and benzene) and recrystallization from hexane. The analytical and spectral properties of **8** [^{1}H NMR ($CDCl_3$) δ 10.4 (1 H, br s, CO_2H), 7.31 (5 H, br s), 6.09 (4 H, AB q, $\Delta\nu$ = 11.0 Hz, J = 10.2 Hz), 2.08 (6 H, br s); λ_{max}^{EtOH} 269 nm (ϵ 1250); mass spectrum, molecular ion *m/e* 240] agree with expectations[7] for the assigned structure. We conclude from isolation of **8** that synthesis of the spiro anion **6** has been achieved. Other experiments in which the product from reaction with Cs–K–Na alloy was carbonated at different time intervals showed that **6** disappeared in THF at −75 °C with a half-life of about 13 min and had a shorter lifetime at higher temperatures.

Since cyclopropyl and cyclobutyl rings have about the same total ring strain,[8] success in synthesis of **6** encouraged us to attempt a similar synthesis of the lower homologue (*p*-phenyl derivative of **3**) even though previous attempts had been unsuccessful at −65 °C and a reaction time of about 30 min.[9] Reaction of 2-chloro-1-*p*-biphenylylethane with excess Cs–K–Na alloy in THF at −75 °C for 1 min before carbonation gave less than 1% (if any) of the desired spiro anion even though some 70% of the starting chloride had been consumed.

Maercker et al.[10] have recently succeeded in stabilizing the cyclopropylmethyl form of a 3-butenyl Grignard reagent by introduction of two *gem*-dimethyl groups (Thorpe–Ingold effect[11]) onto the cyclopropyl ring. Accordingly, synthesis of the spriro anion **7** was undertaken. The necessary chloride, 3-chloro-2-*p*-biphenylyl-2,3-dimethylbutane (**9**), was synthesized starting with the known[12] 2-*p*-biphenylyl-2-propanol, which was converted to its methyl ether. The ether was cleaved with Na–K in diethyl ether and the anion carbonated to give 2-methyl-2-*p*-biphenylylpropanoic acid (mp 170.5–171.8 °C). The acid was esterified to give the methyl ester (mp 70.5–71.5 °C), which upon reaction with methylmagnesium iodide gave 3-*p*-biphenylyl-2,3-dimethyl-2-butanol (mp 71–72 °C). The latter, upon reaction with thionyl chloride in chloroform, gave the desired chloride **9**, mp 110–111 °C. The analytical and