[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF COLORADO]

Mechanisms of Elimination Reactions. XVI. Reaction of Sodium Iodide with *cis*- and *trans*-2-Bromo-1-cyclohexyl Nitrates and Arenesulfonates[1]

BY STANLEY J. CRISTOL, JOHN Q. WEBER AND MARGARET C. BRINDELL

RECEIVED APRIL 18, 1955

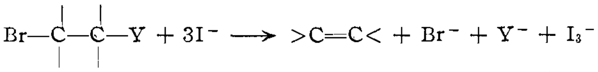
Rates of reaction with sodium iodide in *n*-propyl alcohol of *cis*- and *trans*-2-bromocyclohexyl nitrates, *p*-toluenesulfonates, and *p*-bromobenzenesulfonates and of *trans*-1,2-dibromocyclohexane were measured at various temperatures. Rates of elimination were 40 to 70 times faster with the *trans*-bromohydrin arenesulfonates than with the corresponding *cis* isomers, while both isomers of the bromohydrin nitrates reacted at substantially identical rates. The relatively low (or negligible) differences in reactivity are rationalized in terms of a rate-determining displacement of arenesulfonate or of bromide by iodide preceding elimination in appropriate cases.

W. G. Young and his co-workers[2] have studied the rates and products of elimination of bromine from acyclic dibromides with potassium iodide in methanol and with zinc–copper couple in ethanol, and they have shown that elimination proceeds largely in a *trans* fashion, although some of the reactions were not entirely stereospecific.[2e] Schubert and his co-workers[3] have studied debromination with zinc (in water), magnesium (in tetrahydrofuran) and sodium in ammonia with acyclic dibromides with respect to the stereochemistry of the elimination process. Elimination of other groups by these reagents apparently has not been studied systematically, and elimination from *cis* and *trans* isomers of cyclic dibromides could not be compared because of the unavailability (until recently[4]) of such *cis*-dibromides.

It has been shown,[5] for example, that both *cis*- and *trans*-11,12-dichloro-9,10-dihydro-9,10-ethanoanthracene react with zinc to give the corresponding olefin (9,10-dihydro-9,10-ethenoanthracene), but it did not seem wise to make the generalization from this example that stereospecific *trans* elimination is not required with dihalides and zinc, as this is the system where *cis* alkaline dehydrochlorination is favored over *trans*.[5]

For these reasons it was decided to undertake a study of elimination from derivatives of *cis*- and *trans*-2-bromocyclohexanol with zinc and with iodide ion. The zinc-promoted elimination studies will be reported in a separate communication[6]; the work with iodide ion is described in this paper.

After some preliminary experiments with acetone and methanol, *n*-propyl alcohol was chosen as solvent, and sodium iodide as reagent. Studies were made with *trans*-1,2-dibromocyclohexane to calibrate this procedure with that used previously. No substantial difference was observed.[7] Data on all of the compounds run are listed in Table I. The stoichiometric equation for the over-all reactions is



$$\mathrm{Br{-}\overset{|}{\underset{|}{C}}{-}\overset{|}{\underset{|}{C}}{-}Y} + 3I^- \longrightarrow \mathrm{>C{=}C<} + Br^- + Y^- + I_3^- \qquad (1)$$

and the extent of reaction was followed by titration with standard sodium thiosulfate solution. Calculations of rate constants were conducted as described by Young,[2] but no corrections for salt effects[2c] appeared necessary. The rates were generally followed to 20–60% reaction, depending upon the reaction temperature, as beyond these values the linear plots fell off badly. The rate constants are corrected for temperature expansion of solvent, when necessary. The rate constants are probably good to within 5–10%, except for those with the nitrate ester, where the errors appeared to be somewhat greater. For this reason, differences in the activation energy for isomers recorded in Table I probably are not significant.

Reaction rate constants at 70.0° read off activation energy plots of the data of Table I are given in Table II. A comparison of reactivities may be made from the data in this table. It is to be noted that in the *p*-toluenesulfonate series, the *trans* isomer eliminates 62 times as fast as the *cis* isomer; an analogous ratio of 48 is observed in the *p*-bromobenzenesulfonate series; these latter compounds eliminate about 4 times as rapidly as the *p*-toluenesulfonates and the *trans* isomer about 90 times as fast as the *trans* dibromide. The *cis* and *trans* bromo nitrates react at substantially the same rate and about $^1/_{30}$ as fast as the *cis*-bromo *p*-bromobenzenesulfonate.

Although elimination of *trans* groups is definitely favored over *cis* groups with the arenesulfonates, the rate ratios appear to be several orders of magnitude too small when compared with those often observed in base-promoted dehydrohalogenation,[10] and even this slight advantage vanishes with the nitrates. Accordingly one must assume that debromination with iodide represents a non-stereospecific elimination, or else that the elimination process may be stereospecific, but, in certain cases at least, is not the rate-determining step of the over-all reaction. The literature teaches that the first alternative must be rejected. As mentioned above, Young and his co-workers[2] have shown that elimination proceeds largely in a stereospecific *trans* fash-

---

(1) Previous paper in series: S. J. Cristol and R. F. Helmreich, THIS JOURNAL, **77**, 5034 (1955).

(2) (a) W. G. Young and S. Winstein, *ibid.*, **58**, 102 (1936); (b) W. G. Young, Z. Jasaitis and L. Levanas, *ibid.*, **59**, 403 (1937); (c) W. G. Young, D. Pressman and C. D. Coryell, *ibid.*, **61**, 1640 (1939); (d) S. Winstein, D. Pressman and W. G. Young, *ibid.*, **61**, 1645 (1939); (e) W. G. Young, S. J. Cristol and T. S. Skei, *ibid.*, **65**, 2099 (1943).

(3) W. M. Schubert, B. S. Rabinovitch, N. R. Larson and V. A. Sims, *ibid.*, **74**, 4590 (1952).

(4) H. L. Goering, P. I. Abell and B. F. Aycock, *ibid.*, **74**, 3588 (1952).

(5) S. J. Cristol and N. L. Hause, *ibid.*, **74**, 2193 (1952).

(6) S. J. Cristol and L. E. Rademacher, unpublished.

(7) The rate constants in *n*-propyl alcohol were observed to be less than 10% higher than those in methanol.[8,9]

(8) S. Winstein, *ibid.*, **64**, 2792 (1942).

(9) J. Weinstock, R. G. Pearson and F. G. Bordwell, *ibid.*, **76**, 748 (1954).

(10) See, for example: S. J. Cristol, *ibid.*, **69**, 338 (1947); S. J. Cristol, N. L. Hause and J. S. Meek, *ibid.*, **73**, 674 (1951).

TABLE I

DATA AND REACTION RATE CONSTANTS FOR ELIMINATION WITH SODIUM IODIDE IN *n*-PROPYL ALCOHOL OF SOME 2-SUBSTITUTED 1-BROMOCYCLOHEXANES

2-Substituent	Isomer	Temp., °C.	Initial concn., compd.	*M* NaI	10^5k, l./mole/sec.	$E_{act.}$, kcal./mole
Bromo	*trans*	62.37	0.0216	0.262	0.143	25.9
			.0213	.220	.156	
			.0237	.346	.147	
			.0189	.305	.153	
			.0182	.473	.142	
				Av.	.148	
		74.15	0.0267	0.250	0.601	
			.0304	.308	.585	
				Av.	.593	
		88.17	0.0258	0.185	2.31	
			.0337	.234	2.37	
				Av.	2.34	
p-Toluenesulfonoxy	*trans*	48.86	0.184	0.203	0.768	24.0
			.0275	.288	.777	
				Av.	.773	
		62.37	0.0192	0.270	3.77	
			.0222	.411	3.80	
			.0187	.305	3.82	
				Av.	3.80	
		74.15	0.0196	0.253	12.1	
			.0214	.288	12.3	
				Av.	12.2	
	cis	62.37	0.0222	0.270	0.0648	23.1
			.0149	.155	.0587	
			.0151	.245	.0623	
				Av.	.0619	
		88.17	0.0195	0.185	0.736	
			.0188	.234	.769	
				Av.	.750	
p-Bromobenzenesulfonoxy	*trans*	48.86	0.0201	0.203	3.35	23.0
			.0196	.288	3.40	
				Av.	3.38	
		62.37	0.0147	0.473	15.7	
			.0159	.245	15.6	
			.0175	.154	15.4	
				Av.	15.6	
		74.15	0.0237	0.253	47.2	
			.0205	.288	47.2	
				Av.	47.2	
	cis	62.37	0.0170	0.155	0.307	23.5
			.0138	.245	.299	
				Av.	.303	
		74.15	0.0157	0.250	1.06	
			.0160	.308	1.07	
				Av.	1.07	
		88.17	0.0163	0.231	3.84	
			.0183	.228	3.68	
			.0211	.213	3.77	
			.0299	.301	3.79	
				Av.	3.77	
Nitroxy	*trans*	115.85	0.0293	0.235	3.63	32.4
			.0270	.214	3.86	
			.0291	.214	4.15	
			.0263	.232	3.49	
				Av.	3.79	
		87.99	0.0220	0.215	0.177	
			.0289	.201	.113	
			.0279	.214	.159	
				Av.	.150	
	cis	115.85	0.0293	0.235	3.91	31.7
			.0286	.214	3.99	
			.0300	.214	3.67	
			.0261	.234	3.62	
				Av.	3.80	
		87.99	0.0285	0.215	0.196	
			.0267	.201	.121	
			.0274	.214	.162	
				Av.	.160	

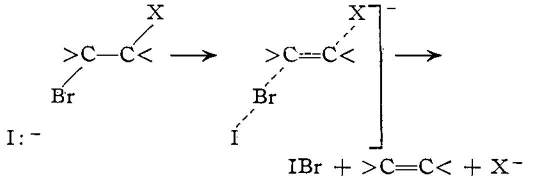
TABLE II

REACTION RATE CONSTANTS FOR ELIMINATION WITH SODIUM IODIDE IN *n*-PROPYL ALCOHOL AT 70°

Compound	10^5k, l./sec./mole	k_{trans}/k_{cis}
trans-1,2-Dibromocyclohexane	0.363	
trans-2-Bromocyclohexyl *p*-toluenesulfonate	8.20	62
cis-2-Bromocyclohexyl *p*-toluenesulfonate	0.132	
trans-2-Bromocyclohexyl *p*-bromobenzenesulfonate	32.9	48
cis-2-Bromocyclohexyl *p*-bromobenzenesulfonate	0.692	
trans-2-Bromocyclohexyl nitrate	.014[a]	1
cis-2-Bromocyclohexyl nitrate	.016[a]	

[a] These values are extrapolated, and probably are not as valid as the others in the table.

ion in acyclic systems, and the rates of elimination from *trans*-1,2-dibromocyclohexane and from *sym*-dibromodialkylethanes do not differ substantially in rate.[2,8] Further, Barton and his co-workers[11] have shown that elimination with iodide ion from rigid cyclocyclic dibromides proceeds at negligibly small rates unless the bromine atoms are *trans* and hold axial–axial conformations—that is, permit *concerted trans coplanar* transition states in elimination. The latter evidence, in particular, appears to compel a stereospecific process for the elimination in a second-order reaction of the type proposed by Young[2]



(2)

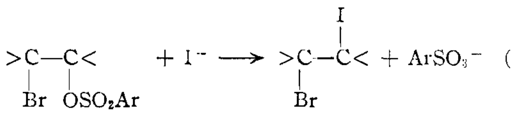
and this process is compatible with the results obtained by us for the *trans* isomers of 1,2-dibromocyclohexane, 2-bromocyclohexyl *p*-toluenesulfonate (OTs) and 2-bromocyclohexyl *p*-bromobenzenesul-

---

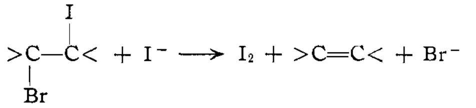
(11) D. H. R. Barton and E. Miller, THIS JOURNAL, **72**, 1066 (1950); D. H. R. Barton and W. J. Rosenfelder, *J. Chem. Soc.*, 1048 (1951); G. H. Alt and D. H. R. Barton, *ibid.*, 4284 (1954).

fonate (OBs). The ratios of reactivity with variation in X = Br:OTs:OBs of 1:23:90 appear to be consistent with the concerted elimination process of equation 2, where the carbon–X bond is being broken (or, of course, with any process in which this bond would be broken).[12]

A reasonable path for the over-all *cis* elimination might involve rate-determining displacement by iodide ion upon carbon with inversion, displacing arenesulfonate and yielding *trans*-iodobromide (equation 3) which would then undergo *trans* concerted elimination with iodide ion (equation 4).



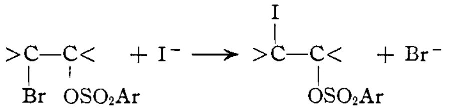
$$>\underset{Br}{C}-\underset{OSO_2Ar}{C}< + I^- \longrightarrow >\underset{Br}{C}-\overset{I}{C}< + ArSO_3^- \quad (3)$$



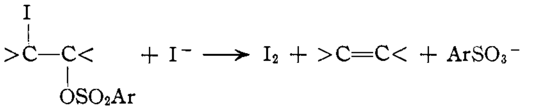
$$>\underset{Br}{C}-\overset{I}{C}< + I^- \longrightarrow I_2 + >C{=}C< + Br^- \quad (4)$$

The latter possibility requires that the *trans*-iodobromide reacts significantly more rapidly than the *trans*-dibromide, which is only one-half as reactive as the *cis*-bromo *p*-bromobenzenesulfonate.[13]

If step (3) were not rate determining (assuming the mechanism correct), but were rapid and irreversible, and step (4) were rate determining, both the *p*-toluenesulfonate and *p*-bromobenzenesulfonate would have equal reactivities. This is not in accord with the facts. An alternative mechanism would involve displacement of bromide by iodide as in (5) followed by elimination as in equation 6



$$>\underset{Br}{C}-\underset{OSO_2Ar}{C}< + I^- \longrightarrow >\overset{I}{C}-\underset{OSO_2Ar}{C}< + Br^- \quad (5)$$



$$>\overset{I}{C}-\underset{OSO_2Ar}{C}< + I^- \longrightarrow I_2 + >C{=}C< + ArSO_3^- \quad (6)$$

Step (6) seems unlikely as rate determining, as the *trans*-iodo arenesulfonate would undoubtedly react more rapidly than the corresponding bromo compound. Hence (5) must be rate determining in this process. The factor of 4 in reactivity ratio of *p*-bromobenzenesulfonate *vs.* *p*-toluenesulfonate seems too high for differences in step (5), but is consistent for a rate-determining step (3).[12a] Thus only the process summarized in steps (3) and (4) seems reasonable.

The data on the bromonitrates can be accommodated by the assumption that the rate-determining step in either case involves displacement of either bromide or nitrate (more likely bromide[17]) by iodide. This would yield a *trans*-iodo compound from the *cis* compound which could rapidly undergo concerted elimination. The *cis*-iodo compound resulting from displacement on the *trans* isomer might be expected to epimerize with iodide ion in a relatively fast process and thus render unimportant the question of whether *cis*- or *trans*-iodo compound is formed. The data do not distinguish between this possibility and the possibility of a relatively slow elimination with the *trans* isomer and a comparable slow displacement with the *cis* isomer.

The rate constants in the nitrate cases are lower than the others because of the relative ineffectiveness of nitrate as a displaceable group compared with bromide or arenesulfonate (in *trans* concerted elimination) or that of bromide or nitrate compared with arenesulfonate (in the first step of the process with the *cis* isomers).

The concept of displacement preceding certain eliminations in these cyclic systems finds considerable support in recent work of Hine and Brader.[18]

Linstead, Owen and Webb[19] have reported that the dimethanesulfonates of the stereoisomeric α,β-dihydroxybutyric acids and α,β-dihydroxy-β-phenylpropionic acids react with sodium iodide in acetone to give the corresponding *cis* and *trans* α,β-unsaturated acids with over-all *cis* elimination of the alkanesulfonoxy groups. Their stereochemical results may be interpreted by assuming a displacement (with inversion) of one of the alkanesulfonoxy groups by iodide, followed by *trans* elimination of iodine and the remaining sulfonoxy group.[20]

Acknowledgments.—The authors are indebted to the Office of Naval Research and the Office of Ordnance Research, U. S. Army, for partial support of this work.

Experimental

Preparation of Materials.—*trans*-2-Bromocyclohexyl *p*-bromobenzenesulfonate,[21] *cis*-2-bromocyclohexyl *p*-bromobenzenesulfonate,[22] and the corresponding *p*-toluenesulfonates were prepared from the appropriate 2-bromocyclohexanols[23,24] with the arenesulfonyl chloride and pyridine. The *p*-toluenesulfonates were apparently new compounds. *trans* Isomer, m.p. 44–45°.

Anal. Calcd. for $C_{13}H_{17}O_3SBr$: C, 46.85; H, 5.14. Found: C, 46.79; H, 5.00.

cis Isomer, m.p. 79–80°.

Anal. Calcd. for $C_{13}H_{17}O_3SBr$: C, 46.85; H, 5.14. Found: C, 46.97; H, 5.24.

trans-1,2-Dibromohexane was prepared by adding bromine to cyclohexene.[23]

Eastman Kodak Co. white label *n*-propyl alcohol, n^{20}D

---

[12] See, for example: (a) M. S. Morgan and L. M. Fletcher, THIS JOURNAL, **70**, 375 (1948); (b) C. H. Grant and C. N. Hinshelwood, *J. Chem. Soc.*, 258 (1933).

[13] It seems reasonable that the *trans*-iodobromide would indeed react more rapidly than the dibromide. Comparable data are available from studies by Slator[14] who found that ethylene iodobromide reacted with potassium iodide in 71% (by volume) ethanol with a rate constant of about 40 × 10^{-5} l./sec./mole at 30° and from studies by Dillon[15] who determined the rate for ethylene dibromide in 63 and 99% (weight per cent.) methanol as 0.43 and 0.28 × 10^{-5} l./sec./mole, respectively. As we have found that rate constants for cyclohexene dibromide in 100% *n*-propyl alcohol and 99% methanol are almost identical, one may predict that the iodobromide would react at least 100 times as rapidly as the dibromide and that the mechanism suggested in (3) and (4), with step (3) rate determining, is very reasonable.[16]

[14] A. Slator, *J. Chem. Soc.*, 86, 1697 (1904).

[15] R. T. Dillon, THIS JOURNAL, **54**, 952 (1932).

[16] See also C. F. van Duin, *Rec. trav. chim.*, 43, 341 (1924).

[17] J. W. Baker and D. M. Easty, *J. Chem. Soc.*, 1193 (1952).

[18] J. Hine and W. H. Brader, Jr., THIS JOURNAL, **77**, 361 (1955).

[19] R. P. Linstead, L. N. Owen and R. F. Webb, *J. Chem. Soc.*, 1211 (1953).

[20] We are indebted to Dr. D. Y. Curtin for drawing our attention to this work.

[21] S. Winstein, E. Grunwald and L. L. Ingraham, THIS JOURNAL, **70**, 821 (1948).

[22] E. Grunwald, *ibid.*, **73**, 5458 (1951).

[23] S. Winstein and R. E. Buckles, *ibid.*, **64**, 2780 (1942).

[24] R. B. Loftfield, private communication.

1.3855, was used as solvent. Sodium iodide, reagent grade, was dried overnight at 105° before use. The nitrate esters, prepared by nitration of the bromohydrins, were kindly furnished by Dr. Boris Franzus.

Reaction Rate Studies.—The reactions were run and the rates calculated substantially as described by Young.[2c] No salt corrections[2c] were made, nor did any appear necessary. In runs below 90°, the solutions were prepared at the reaction temperature in volumetric flasks and run in ground-glass stoppered volumetric flasks. At higher temperatures sealed tubes were used; as well as in some runs at 88°. The principal advantage of the use of *n*-propyl alcohol over methyl alcohol resides in its lower volatility.

The order of the reactions may be noted from the constancy of the rate constants with variation of reagent concentration (Table I).

Reaction of Iodine with Solvents.—An acetone solution, 0.005 *M* in iodine and 0.21 *M* in sodium iodide, lost about 50% of its iodine in 70 hours at 62.4°. A solution (in 99% aq. methanol), 0.025 *M* in iodine and 0.265 *M* in sodium iodide lost less than 2% of its iodine in 200 hours at 62.4°. A solution (in *n*-propyl alcohol), 0.065 *M* in iodine and 0.26 *M* in sodium iodide, lost less than 1% of its iodine in 200 hours at 62.4°.

BOULDER, COLORADO

[CONTRIBUTION FROM THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY (NO. 2028) AND THE DEPARTMENT OF CHEMISTRY AND LABORATORY FOR NUCLEAR SCIENCE AND ENGINEERING, MASSACHUSETTS INSTITUTE OF TECHNOLOGY]

The Mechanism of Aminations of Halobenzenes[1]

BY JOHN D. ROBERTS,[2a] DOROTHY A. SEMENOW,[2b] HOWARD E. SIMMONS, JR., AND L. A. CARLSMITH

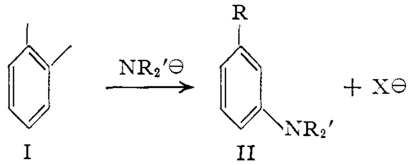
RECEIVED AUGUST 22, 1955

An elimination-addition mechanism, probably involving a "benzyne" intermediate, has been established for the rearrangements which often occur in the conversion of non-activated aryl halides to arylamines with metallic amides. The evidence for the "benzyne" intermediate was obtained through ^{14}C-tracer studies of rearrangements with halobenzenes and experiments designed to determine the role of the hydrogen atom located *ortho* to the displaced halogen atom.

Introduction

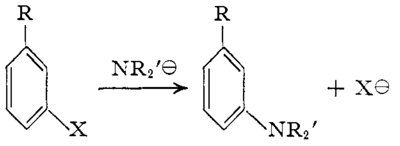
While a large number of the reported rearrangements in reactions of organic halides are initiated by electrophilic reagents, only a small number are initiated by strong nucleophilic reagents. Probably the most important examples of the latter are provided by aminations of non-activated aromatic halides with metallic amides. The first reports of such rearrangements were for aminations which proceed in low yields at high temperatures.[3] These rearrangements were not extensively investigated until it was found[4] that aryl halides could be aminated in fair to good yields with excess sodium or potassium amide in liquid ammonia or with lithium diethylamide in diethyl ether.

The reported rearrangements in aminations of aryl halides show a remarkable independence of the nature of the substituent groups, the halogens, the solvents and the metallic amides. Upon treatment with sodium or potassium amide in liquid ammonia or with lithium diethylamide in ether, *o*-substituted halobenzenes I with the substituent R = $-OCH_3$,[5] $-OC_6H_5$,[5] $-OH$,[6] $-N(CH_3)_2$,[7] $-CF_3$,[8] $-SCH_3$[9] or $-SO_2CH_3$[9] and with X = I, Br or Cl give *m*-substituted anilines II free of the corresponding *o*- and *p*-isomers.[10]



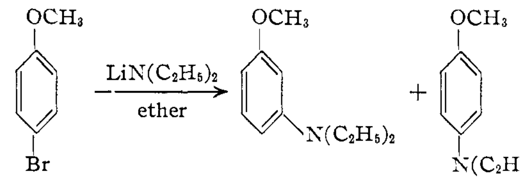
I II

Similarly, 2-bromo-5-trifluoromethylanisole and 2-bromo-6-methylanisole give the corresponding 3-aminoanisoles.[11] The aminations of *m*-substituted halobenzenes (III, R = $-OCH_3$,[7] $-CF_3$[8]) produce the corresponding *m*-anilines II with no detectable amounts of rearrangement products.



III II

In the only published account of an amination of a *p*-substituted phenyl halide, it was reported that *p*-bromoanisole gives a 1:1 mixture of the *m*- and *p*-N,N-diethylaminoanisoles containing no *o*-N,N-diethylaminoanisole.[6]



The pattern of the rearrangements shows a considerable disregard for the influences governing the usual aromatic substitutions, as illustrated by the fact that halobenzenes with *o*-substituent groups, which are *either* strongly *o,p*-directing ($-OCH_3$ and -N-

---

[1] Supported in part by the program of research of the U. S. Atomic Energy Commission. Presented in part at the Kansas City Meeting of the American Chemical Society, March 24, 1954.

[2] (a) Gates and Crellin Laboratories of Chemistry, California Institute of Technology. (b) Skinner Fellow of Mt. Holyoke College, 1953–1954; National Science Foundation Predoctoral Fellow, 1954–1955.

[3] O. Kym, *J. prakt. Chem.*, **51**, 325 (1895); C. Haeussermann, *Ber.*, **32**, 1912 (1899); **33**, 939 (1900); **34**, 38 (1901).

[4] F. W. Bergstrom, R. E. Wright, C. Chandler and W. A. Gilkey, *J. Org. Chem.*, **1**, 170 (1936).

[5] H. Gilman and S. Avakian, THIS JOURNAL, **67**, 349 (1945).

[6] H. Gilman and R. H. Kyle, *ibid.*, **70**, 3945 (1948).

[7] H. Gilman, R. H. Kyle and R. A. Benkeser, *ibid.*, **68**, 143 (1946).

[8] R. A. Benkeser and R. G. Severson, *ibid.*, **71**, 3838 (1949).

[9] G. A. Martin, *Iowa State Coll. J. Sci.*, **21**, 38 (1946).

[10] Rearrangements similar to those observed with substituted halobenzenes have been reported in aminations of dibenzofuran[1] and dibenzothiophene derivatives; H. Gilman and J. F. Nobis, THIS JOURNAL, **67**, 1479 (1945).

[11] R. A. Benkeser and W. E. Buting, *ibid.*, **74**, 3011 (1952).