[CONTRIBUTION FROM THE GEORGE HERBERT JONES LABORATORY OF THE UNIVERSITY OF CHICAGO]

Reactions of Atoms and Free Radicals in Solution. XXXVIII. The Reactions of *trans*-1,2- and 1,3-Dibromocyclohexanes With Grignard Reagents in the Presence of Cobaltous Bromide

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The addition of hydrogen bromide to 3-bromocyclohexene under "peroxidic" and "antioxidant" conditions gave exclusively *trans*-1,3-dibromocyclohexane. The reaction of *trans*-1,2-dibromocyclohexane with isopropylmagnesium bromide (in the presence of 5 mole-% of $CoBr_2$) gave cyclohexene (73%), and equivalent amounts of propane and propylene. The reaction of *trans*-1,3-dibromocyclohexane with isopropylmagnesium bromide (in the presence of 5 mole-% $CoBr_2$) gave a gas consisting of equal amounts of propane and propylene, a mixture (47%, calculated on the basis of the dibromide used) consisting of cyclohexane, cyclohexene and 3,1,0-bicyclohexane, and a higher molecular weight material which has as yet not been identified. A mechanism is suggested which accounts for the products formed in these reactions; the work is being continued.

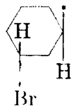
It was noted by Kharasch and Sage[1] that illumination of a mixture of allyl bromide and bromotrichloromethane gave 1,2,3-tribromopropane and 1,1,1,5,5,5 - hexachloro - 3 - bromopentane. The formation of these products was explained on the following basis:

1. $\mathrm{BrCCl_3} \xrightarrow{h\nu} \mathrm{Br\cdot} + \cdot\mathrm{CCl_3}$
2. $\mathrm{CH_2{=}CHCH_2Br} + \cdot\mathrm{CCl_3} \longrightarrow \mathrm{Cl_3CCH_2\underset{\cdot}{C}HCH_2Br}$
3. $\mathrm{Cl_3CCH_2\underset{\cdot}{C}HCH_2Br} + \mathrm{BrCH_2CH{=}CH_2} \longrightarrow \mathrm{Cl_3CCH_2CH{=}CH_2} + \mathrm{BrCH_2\underset{\cdot}{C}HCH_2Br}$
4. $\mathrm{BrCH_2\underset{\cdot}{C}HCH_2Br} + \mathrm{BrCCl_3} \longrightarrow \mathrm{BrCH_2CHBrCH_2Br} + \cdot\mathrm{CCl_3}$
5. $\mathrm{Cl_3CCH_2CH{=}CH_2} + \mathrm{\underset{\cdot}{C}Cl_3} \longrightarrow \mathrm{Cl_3CCH_2{\cdot}CHCH_2CCl_3}$
6. $\mathrm{Cl_3CCH_2\underset{\cdot}{C}HCH_2CCl_3} + \mathrm{BrCCl_3} \longrightarrow \mathrm{Cl_3CCH_2CHBrCH_2CCl_3} + \cdot\mathrm{CCl_3}$

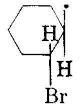
Actually, if an excess of allyl bromide was used in the reaction the only products of the reaction were 1,2,3-tribromopropane and 4,4,4-trichlorobutene-1 (equations 1 to 4).

Step 3 of the scheme given above involves the transfer of a bromine atom to some acceptor molecule. An investigation is underway in this laboratory to determine whether this reaction (step 3) is a general reaction for free radicals of the type $\mathrm{R_2\underset{\cdot}{C}{-}CR_2X}$ and $\mathrm{R_2\underset{\cdot}{C}CH_2CH_2X}$, where X = Br, OH, OR, NR_2, etc.[2]

The present paper deals with the reactions of the free radicals **A** and **B** formed when *trans*-1,3- and *trans*-1,2-dibromocyclohexanes, respectively, are treated with a Grignard reagent in the presence of cobaltous bromide (5 mole-%).

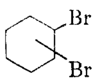


A



B

$$\mathrm{(CH_3)_2CHMgBr} + \mathrm{CoBr_2} \rightarrow \mathrm{(CH_3)_2CH\cdot} + \mathrm{MgBr_2} + \mathrm{(CoBr)\cdot}$$



$$+ \mathrm{(CoBr)\cdot} \longrightarrow \mathbf{A} \text{ or } \mathbf{B} + \mathrm{CoBr_2}$$

Preparation of trans-1,2- and trans-1,3-dibromocyclohexanes. The *trans*-1,2-dibromocyclohexane is readily obtained by the addition of bromine to cyclohexene at low temperatures. The preparation of pure *trans*-1,3-dibromocyclohexane is, however, much more difficult. Treatment of a mixture of the *cis*- and *trans*-1,3-cyclohexanediols (formed by hydrogenation of resorcinol) with hydrogen bromide[3] gives a mixture of *cis*- and *trans*-1,3-dibromocyclohexanes, from which the *cis* compound (which is a solid) may be obtained in a pure form. However, the *trans* compound (which is a liquid) contains varying amounts of the *cis* isomer.

It was thought that the pure *trans*-1,3-dibromocyclohexane could be prepared by the addition of hydrogen bromide to 3-bromocyclohexene.[4]

A study was made of the product (or products) formed by the addition of hydrogen bromide to 3-bromocyclohexene under rigidly "antioxidant" and under "peroxidic" conditions. The first results of these experiments were somewhat ambiguous, since the reaction products darkened upon standing (although the pure 1,2- and 1,3-dibromides are stable in the light), and the indices of refraction of the products increased with time. Since the impurity most likely to lead to darkening of the reaction products was the unreacted 3-bromocyclohexene, the latter was removed from the reaction

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(1) Kharasch and Sage, *J. Org. Chem.*, **14**, 79 (1949).

(2) Note for instance that 3-phenoxypropyl bromide gives phenol and cyclopropane when treated with a Grignard reagent and cobaltous chloride [Kharasch, Stampa, and Nudenberg, *J. Org. Chem.*, **18**, 575 (1953)]. For methods of generation of the free 3-phenoxypropyl radical the paper of Kharasch, Mulley, and Nudenberg, *J. Org. Chem.*, **19**, 1477 (1954) should be consulted. Note also the paper on detection of free radicals in solution by Kharasch, Holton, and Nudenberg, *J. Org. Chem.*, **20**, 920 (1955).

(3) Lindenmann and Baumann, *Ann.*, **477**, 78 (1929).

(4) For pertinent references see: Kharasch and Mayo, *J. Am. Chem. Soc.*, **55**, 2468 (1933); Kharasch, Margolis, and Mayo, *J. Org. Chem.*, **1**, 398 (1937); Kharasch, McNab, and Mayo, *J. Am. Chem. Soc.*, **55**, 2521 (1933); Kharasch, Engelmann, and Mayo, *J. Org. Chem.*, **2**, 288 (1937); Walling, Kharasch, and Mayo, *J. Am. Chem. Soc.*, **61**, 1711 (1939); Kharasch and Fuchs, *J. Org. Chem.*, **13**, 97 (1948) and other papers in this series.

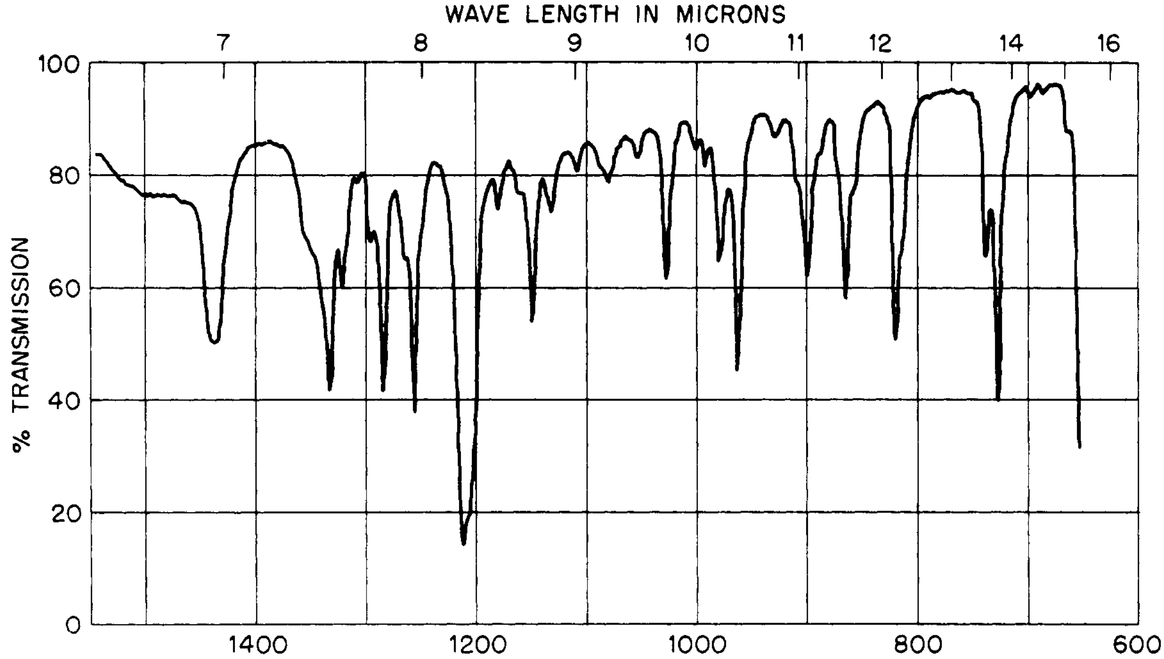


FIG. 1.—INFRARED SPECTRUM OF DIBROMIDE OBTAINED FROM THE ADDITION OF HBr TO 3-BROMOCYCLOHEXENE UNDER ANTIOXIDANT CONDITIONS. CONCENTRATION: 10% IN CARBON DISULFIDE. CELL THICKNESS 0.1 MM.

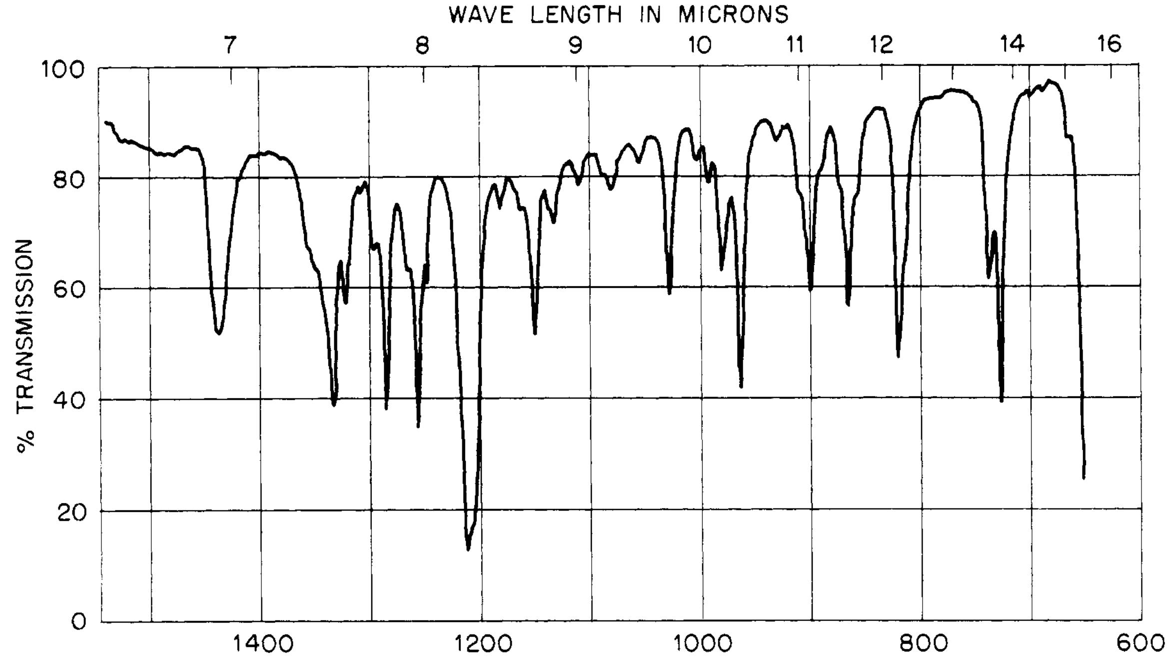


FIG. 2.—INFRARED SPECTRUM OF DIBROMIDE OBTAINED FROM PEROXIDE CATALYZED ADDITION OF HBr TO 3-BROMOCYCLOHEXENE. CONCENTRATION: 10% IN CARBON DISULFIDE. CELL THICKNESS 0.1 MM.

TABLE I

ADDITION OF HYDROGEN BROMIDE TO 3-BROMOCYCLOHEXENE

Solvent	Peroxides	Antioxidant	Yield, %	n_D^{25}	1,3-Dibromocyclohexane (%, est.)
1 n-Hexane	Ascaridol (3 mole-%)	—	80	1.5459	100
2 None	—	TBI + DA[a]	80	1.5462[b]	100

[a] The mixture of antioxidants used in this study, namely *tert*-butyl isocyanide and diphenylamine was the one that gave the best yield of the "normal" addition product in the case of vinyl bromide [Kharasch, McNab, and Mayo, *J. Am. Chem. Soc.*, **55**, 2521 (1933)]. [b] The indices of refraction at 25° given in the literature for 1,2- and 1,3-dibromocyclohexanes are 1.5507 and 1.5465, respectively.

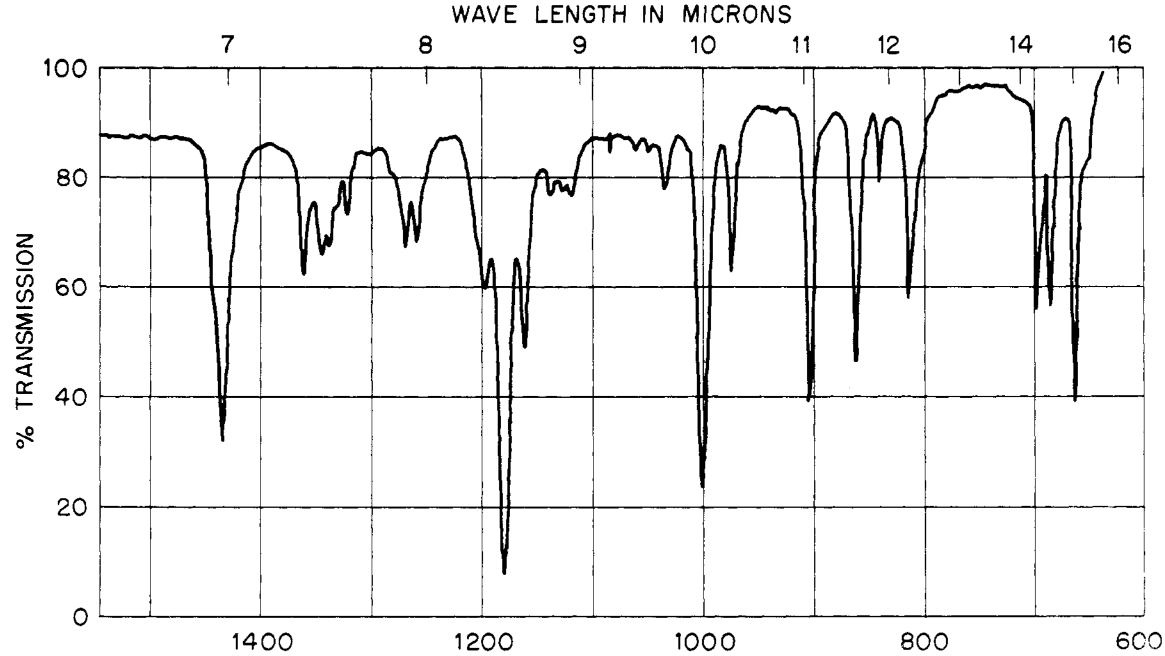


FIG. 3.—INFRARED SPECTRUM OF *trans*-1,2-DIBROMOCYCLOHEXANE. CONCENTRATION: 10% IN CARBON DISULFIDE. CELL THICKNESS 0.1 MM.

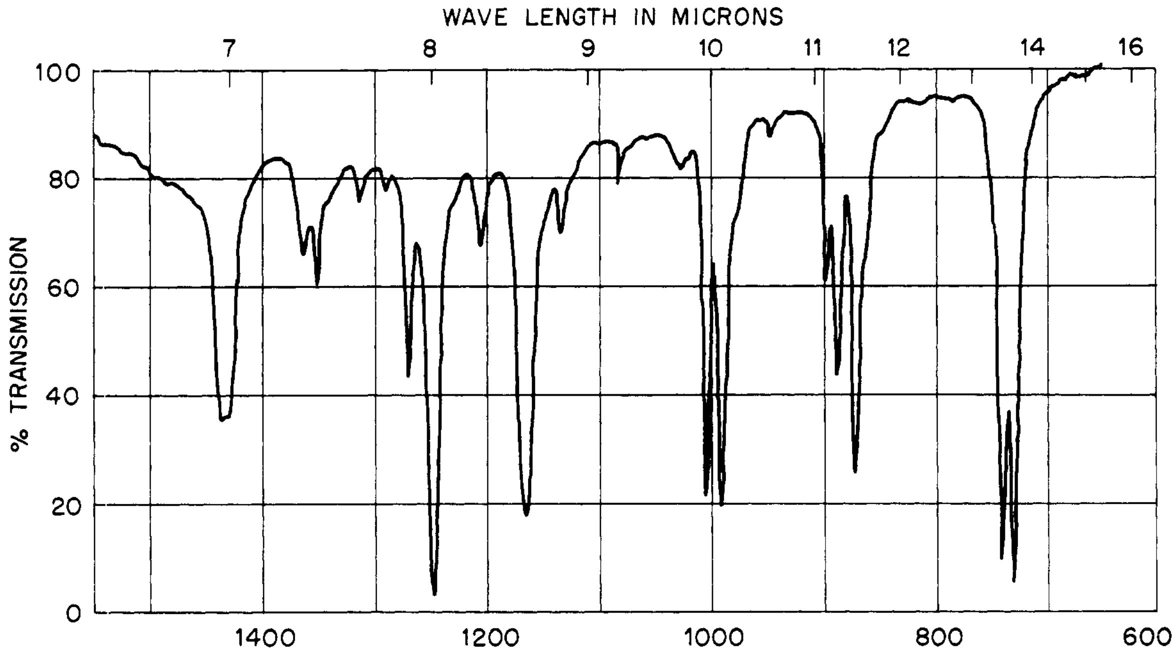
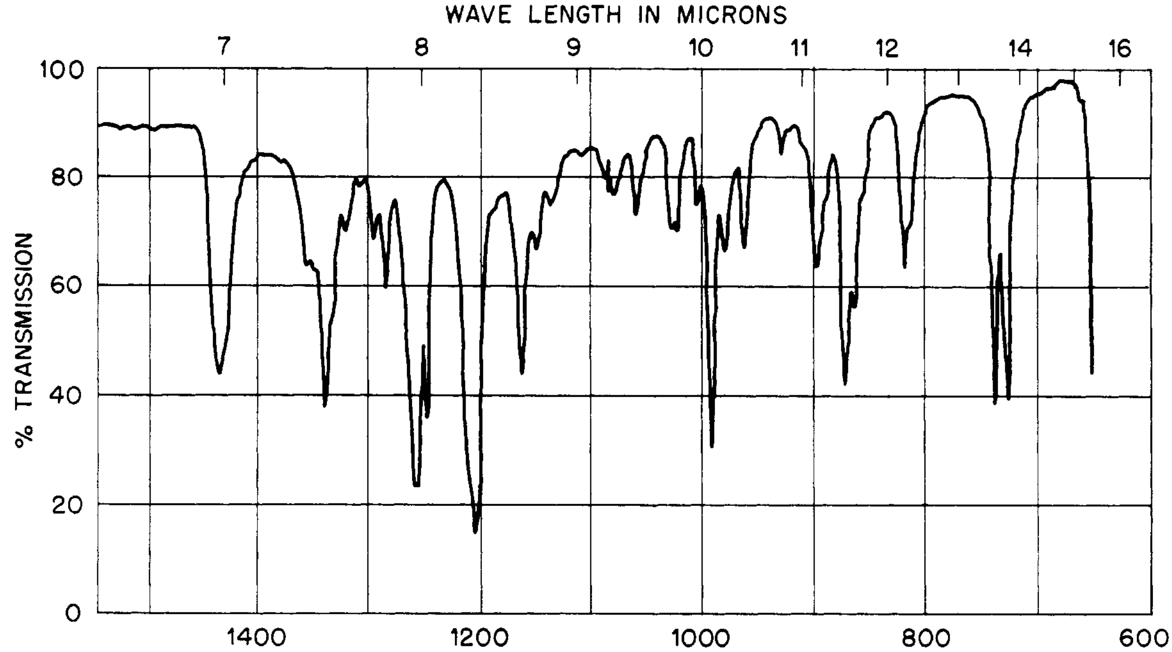


FIG. 4.—INFRARED SPECTRUM OF *cis*-1,3-DIBROMOCYCLOHEXANE PREPARED FROM 1,3-CYCLOHEXANEDIOL. CONCENTRATION: 10% IN CARBON DISULFIDE. CELL THICKNESS 0.1 MM.

mixture by treatment with dimethylaniline. Once this procedure was adopted it became clear (from examination of the indices of refraction) that only one product, namely the 1,3-dibromocyclohexane, was formed by the addition of hydrogen bromide under "antioxidant" and under "peroxidic" conditions (Table I).

The identity of the products formed by the addition of hydrogen bromide to 3-bromocyclohexene under "peroxidic" and "antioxidant" conditions was further confirmed by the identity of the infrared spectra of these products (Figs. 1 and 2).

Evidence that the 1,3-dibromocyclohexane, prepared from 3-bromocyclohexene and hydrogen bromide, is practically pure *trans*-1,3-dibromocyclohexane is derived from examination of the infrared spectra of the compounds in question. The data indicate that less than five percent (if any) of *trans*-1,2-dibromocyclohexane (Figs. 1 and 3), and *cis*-1,3-dibromocyclohexane (Figs. 1 and 6) are present



G. 5.—INFRARED SPECTRUM OF LIQUID (*trans*) 1,3-DIBROMOCYCLOHEXANE PREPARED FROM 1,3-CYCLOHEXANEDIOL. CONCENTRATION: 10% IN CARBON DISULFIDE. CELL THICKNESS 0.1 MM.

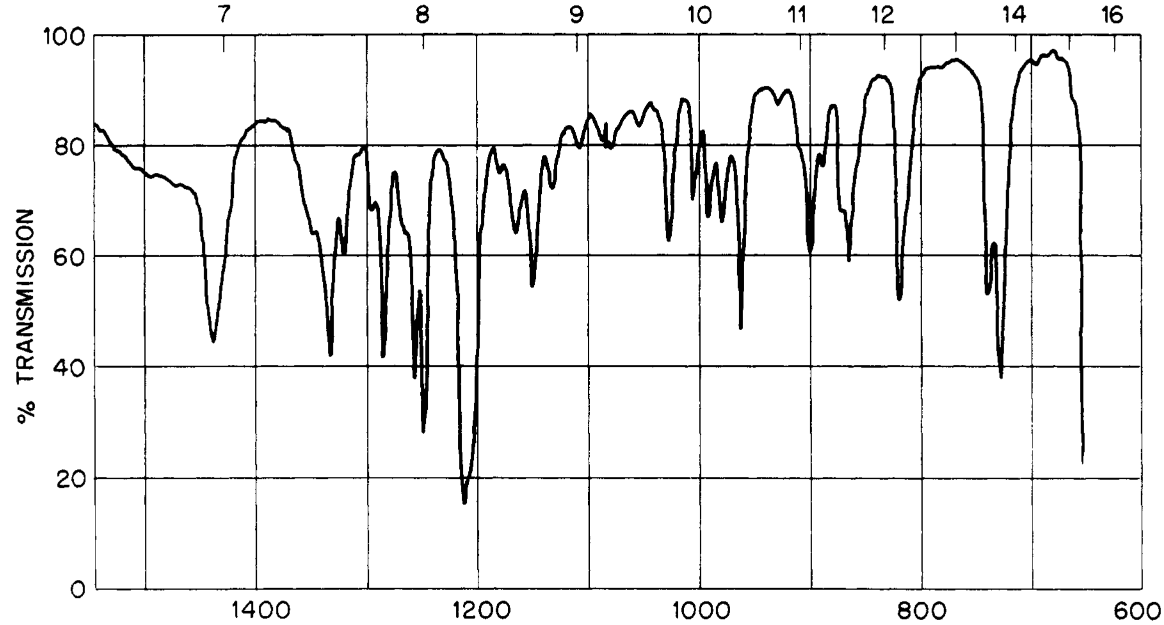


FIG. 6.—INFRARED SPECTRUM OF MIXTURE CONTAINING 90% DIBROMIDE FROM PEROXIDE CATALYZED ADDITION OF HBr TO 3-BROMOCYCLOHEXENE AND 10% *cis*-1,3-DIBROMOCYCLOHEXANE. CONCENTRATION: 10% IN CARBON DISULFIDE. CELL THICKNESS 0.1 MM.

as contaminants.[5] The addition of hydrogen bromide to 3-bromocyclohexene is thus stereospecific and gives rise to the *trans* isomer.

The data here presented do not permit an unequivocal choice, whether both the free radical addition and the ionic addition result in the same product, or whether one of these mechanisms is operating to the exclusion of the other. On the basis of past information[4] it appears likely that the same product could result from an ionic and free radical addition of hydrogen bromide to some systems. Additional work in this field is contemplated.

Reaction of trans-1,2- and trans-1,3-dibromocyclohexanes with isopropylmagnesium bromide in the presence of cobaltous bromide (5 mole-%). When an ether solution of *trans*-1,2-dibromocyclohexane

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[5] Note that the *trans*-1,3-dibromocyclohexane prepared from the 1,3-cyclohexanediol contains some of the *cis* isomer (Fig. 5). The *cis* and *trans* isomer formed from 1,3-cyclohexanediol and hydrogen bromide were separated by crystallization. The *cis* isomer (m.p. 111–112°) was obtained in the pure form.

(0.3 mole) was added slowly to an ethereal solution of isopropylmagnesium bromide (0.7 mole) containing 5 mole-percent of cobaltous bromide (on the basis of the dibromide) evolution of a gas was noted. The evolution of the gas ceased soon after all the dibromide had been added.

The gas was a mixture of equal quantities of propane and propylene. Upon working up the reaction mixture, cyclohexene was obtained[6] (70%, on the basis of the 1,2-dibromide used).

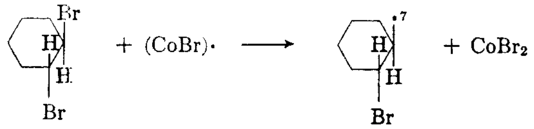
Some of the possible mechanisms which account for the major reaction products are indicated below:

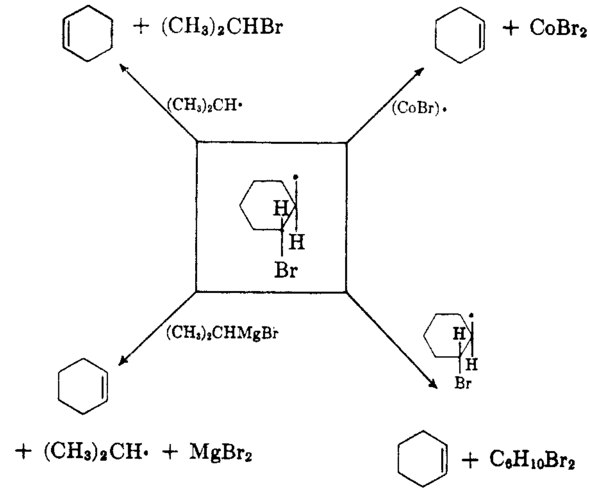
7. $(CH_3)_2CHMgBr + CoBr_2 \longrightarrow (CH_3)_2CHCoBr + MgBr_2$

8. $(CH_3)_2CHCoBr \longrightarrow (CH_3)_2CH\cdot + (CoBr)\cdot$

9. $2(CH_3)_2CH\cdot \longrightarrow C_3H_8 + C_3H_6$

10.





Since all of the reactions indicated in 11 are feasible, and all lead to the same final reaction products, it is impossible at this time to assess the importance of any of them insofar as the final reaction products are concerned.

When *trans*-1,3-dibromocyclohexane was added to isopropylmagnesium bromide (containing 5 mole-percent of cobaltous bromide) a gas was evolved. The gas consisted of equal quantities of propane and propylene. Upon working up the reaction mixture, a hydrocarbon fraction boiling at 78–90° was obtained (47% on the basis of 1,3-dibromide used). Analysis of this fraction (Found: C, 87.22; H, 12.88), and the low refractive index (n_D^{20} 1.4344) suggested that the fraction in question is a mixture of cyclohexane, cyclohexene, and 3,1,0-bicyclohexane.[8] Since the amount of available material was too small for separation of these components by fractional distillation, the approximate composition of the mixture was deduced from the following experiments: (a) Ozonolysis of the original fraction indicated the presence of cyclohexene (25%). (b) From the amount of hydrogen gas (57%) taken up (in acetic acid in the presence of PtO_2) by the material, it follows that 32% of the material must be 3,1,0-bicyclohexane. The remainder (43%) is probably cyclohexane.

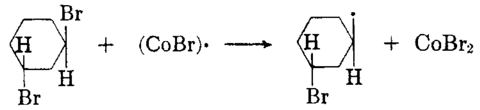
The presence of 3,1,0-bicyclohexane in the mixture was further confirmed by an examination of the infrared spectrum of the mixture (Fig. 7). It will be noted that the material has a peak at 9.8μ. This band is considered to be characteristic of the cyclopropane ring.[9]

Whereas a full detailed account of the reaction is not available as yet (since at this writing we are not fully cognizant of the structures of the higher-boiling materials), nevertheless, the mechanisms whereby the cyclohexane, cyclohexene, and the 3,-1,0-bicyclohexane are formed are readily understood. Thus we believe that the 3,1,0-bicyclohexane is formed as follows:

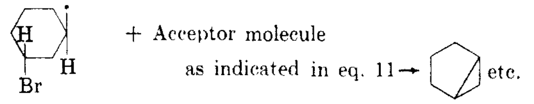
12. $(CH_3)_2CHMgBr + CoBr_2 \longrightarrow (CH_3)_2CHCoBr + MgBr_2$

13. $(CH_3)_2CHCoBr \longrightarrow (CH_3)_2CH\cdot + (CoBr)\cdot$

14.



15.



The work is being continued with particular emphasis on the stereospecific aspects of these reactions, including the nature of the elimination reactions with both the *cis* 1,2- and 1,3-dibromocyclohexanes.

EXPERIMENTAL

Preparation of 3-bromocyclohexene. 3-Bromocyclohexene (b.p. 63–69°/14 mm.; n_D^{25} 1.5298) was prepared from cyclohexene and N-bromosuccinimide.[10] This compound darkens

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(6) The infrared spectrum of the cyclohexene formed in this reaction was identical with the infrared spectrum of an authentic sample of cyclohexene.

(7) For the sake of simplicity, these free radicals are written in this simple form. However, no implications regarding the structure (or structures) of the free radical are to be read into these formulae [Abell, Aycock, and Goering, *J. Am. Chem. Soc.*, **74**, 3588 (1952); Goering and Sims, *J. Am. Chem. Soc.*, **77**, 3465 (1955)]. The speculations regarding possible structures of these, and other free radicals, will be discussed in a forthcoming paper (Kharasch, Liu, Mathur, and Nudenberg).

(8) Zelinsky and Ouchakoff, *Bull. soc. chim. France*, [4], **35**, 484 (1924); *J. Russ. Phys.-Chem. Soc.*, **56**, 167 (1925) claim to have prepared 3,1,0-bicyclohexane from $BrCHCH_2CH_2CH_2CHCH_2Br$ and zinc (b.p. 78.5–79.5°/740 mm.; n^{18}_D 1.4326).

(9) Slabey, *J. Am. Chem. Soc.*, **76**, 3605 (1954).

(10) Ziegler, Spaeth, Schaaf, Schumann, and Winkelmann, *Ann.*, **551**, 80 (1942).

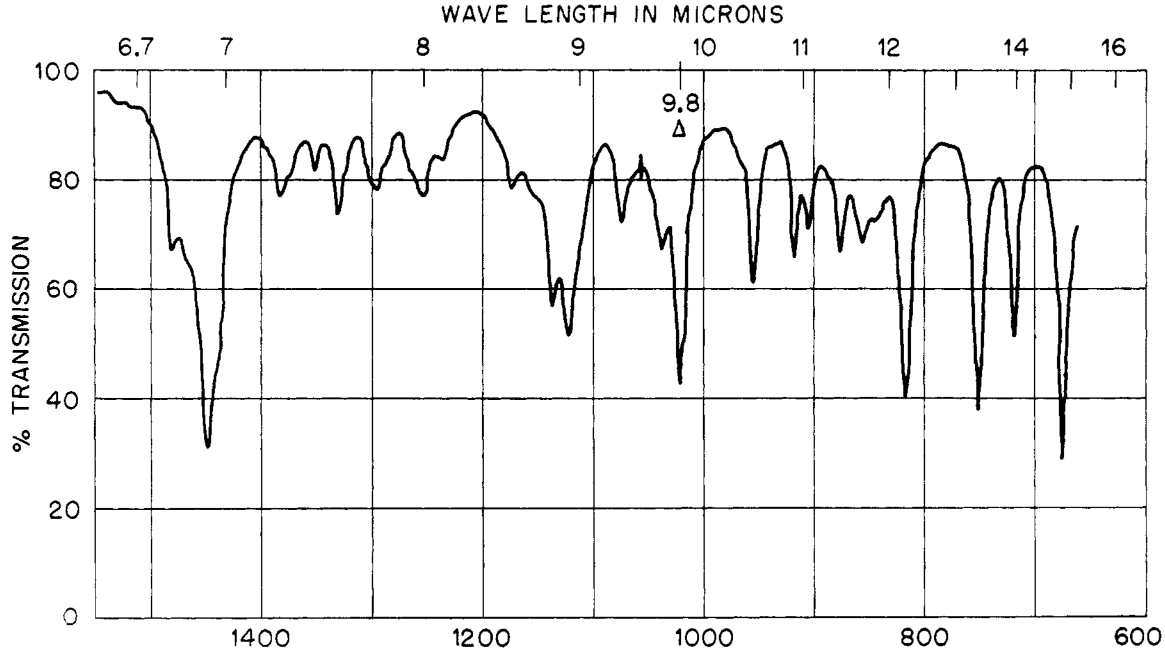

FIG. 7.—INFRARED SPECTRUM OF VOLATILE (B.P. 80°) HYDROCARBON MIXTURE OBTAINED BY DEBROMINATION OF 1,3-DIBROMOCYCLOHEXANE WITH ISOPROPYLMAGNESIUM BROMIDE IN THE PRESENCE OF COBALT BROMIDE. LIQUID FILM 0.025 MM.

rapidly on standing in the light and in the presence of air. However, it can be stored without darkening in a sealed evacuated tube kept in the dark.

Preparation of trans-1,2-dibromocyclohexane. This compound was prepared by the addition of bromine dissolved in carbon tetrachloride to cyclohexene at 0°. The reaction mixture was washed with 20% ethanolic potassium hydroxide and distilled (b.p. 110–112°/23 mm.; n_D^{25} 1.5507).

Preparation of 1,3-dibromocyclohexane. 1,3-Dibromocyclohexane was prepared (b.p. 105–112°/10 mm.; n_D^{25} 1.5465) in 73% yield by the reaction of hexahydroresorcinol[11] with saturated aqueous hydrogen bromide. Upon cooling a solid (m.p. 111.5–112° after crystallization from ethanol) separated from the reaction product. This solid was *cis*-1,3-dibromocyclohexane. (Fig. 4) It is noteworthy that removal of the crystals caused no change in the refractive index of the liquid (n_D^{25} 1.5465). It has been assumed by previous investigators that this liquid is pure *trans*-1,3-dibromocyclohexane, although it probably contains some of the *cis* isomer (see Fig. 5).

Addition of hydrogen bromide to 3-bromocyclohexene under "peroxidic" conditions. 3-Bromocyclohexene (19.1 g.) and *n*-hexane (100 cc.) were placed in a bomb tube and ascaridole (3 mole-% on the basis of 3-bromocyclohexene) was added. The tube was cooled to −90° and a 50% excess (on the basis of 3-bromocyclohexene) of hydrogen bromide was condensed into the bomb tube. The tube was sealed off and allowed to stand at room temperature for ten days. At the end of that time, the tube was cooled to −90° and opened. The contents were poured into 5% aqueous sodium bicarbonate and the whole was extracted into light petroleum ether. The organic solution was washed with 5% aqueous sodium bicarbonate, then with water, and finally was dried over sodium sulfate. The sodium sulfate was collected on a filter, and the filtrate was concentrated at reduced pressure. After removal of the petroleum ether, the *n*-hexane, and most of the unreacted 3-bromocyclohexene, the reaction product was distilled (21 g.; n_D^{25} 1.5465). A small residue remained in the distillation flask.

It appeared impossible to remove the last traces of 3-bromocyclohexene from the reaction product by distillation, as indicated by the darkening of the reaction mixture on standing. It was found that shaking the reaction mixture with dimethylaniline effectively removed this material and that the dibromide so purified no longer darkened on standing (n_D^{25} 1.5459). (For infrared spectrum of this material see Fig. 2.)

Addition of hydrogen bromide to 3-bromocyclohexene under "antioxidant" conditions. Hydrogen bromide (12.0 g.) was condensed at −90° into a bomb tube fitted with a break-off seal, and, after several degassings, the evacuated tube was sealed. 3-Bromocyclohexene (16.7 g.) was put in another bomb tube. Diphenylamine (2 mole-% based on 3-bromocyclohexene) and *tert*-butyl isocyanide (5 mole-% based on 3-bromocyclohexene) were placed in a third bomb tube. The three bomb tubes then were sealed to a yoke attached by means of a stopcock to the vacuum line. The 3-bromocyclohexene and the diphenylamine, *tert*-butyl isocyanide solution were degassed three times and the 3-bromocyclohexene was distilled into the bomb tube containing the diphenylamine and *tert*-butyl isocyanide. The break-off seal was broken and the hydrogen bromide was allowed to distill into the bomb tube containing the reactants. This bomb tube then was sealed. After the bomb tube stood for five days it was opened and worked up by the procedure indicated for the reaction of hydrogen bromide and 3-bromocyclohexene under "peroxidic" conditions (20.7 g.; b.p. 45–53°/0.05 mm.; n_D^{25} 1.5462). (For infrared spectrum of this material see Fig. 1.)

Reaction of trans-1,3-dibromocyclohexane with isopropylmagnesium bromide and cobaltous bromide. The apparatus used for this reaction consisted of a three-necked flask fitted through ground-glass joints, with a "Tru-bore" stirrer, a dropping funnel, and an adapter connected to a reflux condenser and a tube containing cobaltous bromide. The gas evolved in the reaction was collected and analyzed by the method described by Kharasch, Lewis, and Reynolds.[12]

The Grignard reagent (0.7 mole) was introduced into the three-necked flask, the air in the system was displaced by nitrogen, and the cobaltous bromide was added in small

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[11] Kindly supplied by Professor Herman Pines, Northwestern University.

[12] Kharasch, Lewis, and Reynolds, *J. Am. Chem. Soc.*, **65**, 493 (1943).

portions (5 mole-% on the basis of 1,3-dibromocyclohexene). The solution of 1,3-dibromocyclohexane (0.3 mole), dissolved in anhydrous ethyl ether, then was added. The rate of addition of the dibromide was adjusted to maintain the reaction mixture at the boiling point of the ethyl ether. The evolved gas was collected over water saturated with sodium chloride.

Evolution of gas ceased soon after all the dibromide had been added.[13] The mixture then was decomposed with water and dilute acetic acid, the layers were separated, and the ethereal solution was washed first with aqueous sodium bicarbonate, then with water, and finally was dried over sodium sulfate.

The sodium sulfate was collected on a filter, and the ether was distilled from the filtrate through a three-foot Podbielniak column. The residue which remained after distillation of the ether was transferred to a distillation flask and was distilled at reduced pressure (25 mm.). The material (A) which was volatile at room temperature was collected at −80° (11.6 g.; n^{20}_{D} 1.4344). A bromine free "residue" remained in the distillation flask. The "residue" was not investigated further.

Upon distillation of **A** at ordinary pressure it boiled at 78–90° (n^{20}_{D} 1.4344, d^{23}_{4} 0.7878; molecular refraction exaltation = 1.2). (For infrared spectrum of **A** see Fig. 7.)

A weighed sample (1.0 g.) of **A** was dissolved in pure ethanol; ozone was passed through the ethanolic solution at −45° until the escaping current of gas liberated iodine from a potassium iodide solution. From the quantity of ozone absorbed, it was estimated that **A** contained 25% of an olefin (presumably cyclohexene).

A weighed sample (2.95 mmoles) of **A** dissolved in glacial acetic acid was hydrogenated in the presence of platinum oxide at 50°. The amount of hydrogen uptake (1.68 mmoles) in this experiment indicates 57% of unsaturation in **A**. These data suggest that fraction **A** consists of 25% of cyclohexene, 43% of cyclohexane, and 32% of 3,1,0-bicyclohexane.

A procedure similar to the one described above was used in the reaction of isopropylmagnesium bromide with *trans*-1,2-dibromocyclohexane.

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[13] The gas consisted of equimolecular amounts of propane and propylene.