The Stereochemistry of a Bromination–Debromination Sequence Using Radioactive Bromine-82 Tracer[1]

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The stereochemical course of the bromination of 1-bromocyclohexene and the iodide- and zinc-promoted debrominations of the corresponding vicinal dibromide was determined using radioactive bromine-82. The two-step sequence using the iodide ion induced elimination was found to be completely stereospecific, whereas the sequence using zinc metal indicated a lack of stereospecificity in the elimination step.

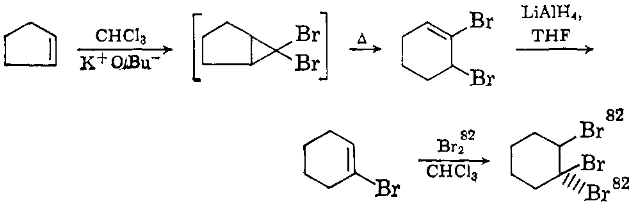
The mechanism of the bromination of olefins is generally accepted as proceeding in a *trans* manner through a bromonium ion intermediate. Barton established the stereochemistry of bromination by the isolation of *trans*-diaxial 1,2-dibromides as major products in the ionic brominations of various cholestenes.[3–5] Subsequent thermal conversion of the diaxial bromides to the stereoisomeric *trans*-diequatorial 1,2-dibromides confirmed the original assignment of stereochemistry.

The iodide-induced elimination of bromine from vicinal dibromides has been shown to follow a *trans* steric course and an E2-like *trans* coplanar elimination has been suggested.[6,7] Barton has also shown that *trans*-diaxial 1,2-dibromides are eliminated by iodide ion much more rapidly than the stereoisomeric *trans*-1,2-diequatorial dibromides.[4,5] Some zinc debrominations have been found to occur in a predominantly *trans* manner,[8,9] and again an E2-like *trans* coplanar elimination mechanism has been suggested.[7]

In connection with another investigation, this work was concerned with determining, quantitatively, the stereospecificity of a bromination–debromination sequence. By the use of bromine-82, a radioactive isotope,[10] the over-all stereospecificity of the bromination of 1-bromocyclohexene and the iodide- and zinc-promoted debrominations of the resulting tribromide was determined. The cyclohexane ring system was chosen to avoid the free rotation of an acyclic system. Further, it could be anticipated that the rigidity of the steroidal ring system, which was exploited by Barton,[3–5] would be unsatisfactory in view of the elevated temperatures necessary for a conveniently rapid debromination reaction.

Results

The synthesis of 1-bromocyclohexene (Ia) was achieved by reduction of the known 2,3-dibromocyclohexene with lithium aluminum hydride in refluxing tetrahydrofuran. The rearrangement of 6,6-dibromobicyclo[3.1.0]hexane upon distillation[11] followed by hydride reduction of the resulting dibromocyclohexene offered a convenient and practical route to the vinyl bromide. Further, the synthetic route would appear to be a more general method for the synthesis of cyclic vinyl bromides[12] than that route employed by Goering and Sims in their preparation of 1-bromocyclohexene.[13] Low-temperature bromination of the vinyl bromide Ia with radioactive bromine-82, a γ emitter with a short half-life,[14] yielded labeled 1,1,2-tribromocyclohexane (IIa).



Ia IIa

Labeled tribromide IIa was subjected to a debromination reaction with sodium iodide in methanol at 110° for 18 hr. The γ activity of the resulting vinyl bromide, Ia, was then measured using the starting labeled IIa as standard. Accordingly, the product vinyl bromide Ia gave 425 c.p.m./mmole and the tribromide standard IIa 140,403 c.p.m./mmole.[15] This indicated that 0.30% of labeled bromine-82 was retained in the vinyl bromide product of the iodide debromination of IIa. After accounting for the probable procedural and experimental errors, the retention of radioactive bromine-82 in the product Ia was 0.3 ± 0.3%.

The zinc debromination of IIa in ethanol at room temperature for 17 hr. gave vinyl bromide Ib which was counted as described above. The 1-bromocyclohexene isolated from this reaction retained 11.5 ± 0.5% of the radioactive bromine which had been present in the starting IIa.

Bromination with unlabeled bromine of the labeled vinyl bromide Ib, obtained from the zinc debromina-

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[2] Ethyl Corporation Fellow, 1963–1964.

[3] D. H. R. Barton and E. Miller, *J. Am. Chem. Soc.*, **72**, 1066 (1950).

[4] D. H. R. Barton and W. J. Rosenfelder, *J. Chem. Soc.*, 1048 (1951).

[5] G. H. Alt and D. H. R. Barton, *ibid.*, 4284 (1954).

[6] W. G. Young, D. Pressman, and C. D. Coryell, *J. Am. Chem. Soc.*, **61**, 1640 (1939).

[7] W. Young, S. J. Cristol, and T. Skei, *ibid.*, **65**, 2099 (1943), and references cited therein.

[8] W. G. Young, Z. Jasaitis, and L. Levanas, *ibid.*, **59**, 404 (1937).

[9] H. O. House and R. S. Ro, *ibid.*, **80**, 182 (1958), and references cited therein.

[10] A previous paper reporting the use of bromine-82 in a mechanistic study is C. L. Stevens, M. E. Munk, A. B. Ash, and R. D. Elliott, *ibid.*, **85**, 3390 (1963).

[11] J. Sonnenberg and S. Winstein, *J. Org. Chem.*, **27**, 748 (1962).

[12] See, for example, W. R. Moore, W. R. Moser, and J. E. LaPrade, *ibid.*, **28**, 2200 (1963).

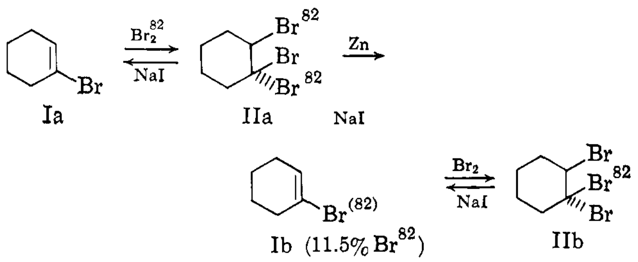
[13] H. L. Goering and L. L. Sims, *J. Am. Chem. Soc.*, **79**, 6270 (1957).

[14] See Experimental section.

[15] This value includes a correction for the presence of two radioactive bromine atoms in IIa.

tion reaction of IIa, gave tribromide IIb. Debromination of IIb with sodium iodide regenerated vinyl bromide Ib which had retained 100.0 ± 1.0% of its bromine-82 label.

The treatment of IIa with unlabeled zinc bromide under forcing conditions resulted in a 0.56 ± 1.4% loss of bromine-82 from the tribromide. Further, treatment of unlabeled IIa with labeled zinc bromide-82 gave a 1.0 ± 0.2% incorporation of radioactive bromine into unlabeled IIa. Finally, exposure of unlabeled 1-bromocyclohexene (Ia) to labeled zinc bromide-82 under reaction conditions gave only a 0.37 ± 0.10% incorporation of bromine-82 after recovery.



Discussion

The *trans*-diaxial stereochemical course for the addition of bromine to double bonds is well-established, and the results of the bromination–iodide elimination sequence reported here serve to extend the knowledge of the bromine addition reaction into the area of vinyl bromides. Thus, the complete stereospecificity of that two-step sequence requires that the bromination step be cleanly *trans*. Further, the interesting possibility of a bromonium ion interchange such as shown in Figure 1 is ruled out in this case[16] since such a process would have resulted in nonstereospecific addition of radioactive bromine.

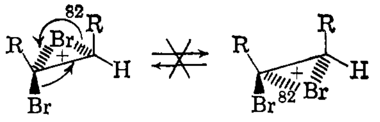


Figure 1.

The results of the iodide debromination were not unexpected. Both Barton[4,5] and Young[17] have demonstrated the stereochemical course of the iodide debromination reaction in certain steroidal and acyclic vicinal dibromides.[18] Our result of 100.0 ± 0.3% stereospecificity for the bromination–iodide debromination sequence permits the calculation of a lower limit for the *trans*/*cis* rate ratio for the debromination. Thus, using the limits for experimental error, a *trans*/*cis* rate ratio of 332 is obtained. This value can be contrasted with the value of 11.5 obtained by Goering[19] for the *trans*/*cis* rate ratio in the iodide debrominations of *trans*- and *cis*-1,2-dibromocyclohexane.[20] The higher ratio of *trans vs. cis* elimination in the case of tribromide IIa can be ascribed to two main factors. First, the ground-state equilibrium concentration of conformer A of IIa (Figure 2) would be expected to be appreciable. Dipole moment measurements in benzene on *trans*-1,2-dibromocyclohexane[21] indicate a nearly $^{50}/_{50}$ mixture of the diaxial and diequatorial conformations. The *two* bromine–bromine *gauche* interactions in conformation B above would probably cause conformation A to be the most energetically favorable. Second, the inductive effect of a bromine atom on its geminal neighbor should result in a more facile nucleophilic attack by iodide ion on the latter bromine atom, perhaps even to the exclusion of attack on the vicinal bromine.[22] The above steric and electronic factors should enhance the rate of *trans*-diaxial elimination of IIa[23] and account for the increased relative rate ratio.

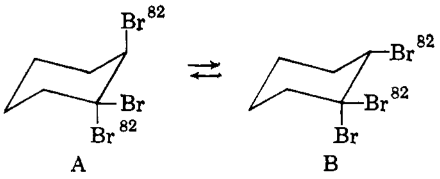


Figure 2.

The stereochemical course of the zinc-promoted debromination reaction has been thoroughly studied[8,9,24] in acyclic systems. This present work appears to represent the first quantitative demonstration of the stereospecificity of the zinc debromination reactions in a cyclic system.[25] While the degree of stereospecificity for the iodide–debromination reaction can be deduced from the data of Goering,[19] analogous data for the zinc reaction is not available. The lack of stereospecificity frequently noted for the acyclic cases,[8,9,24] the kinetic data of Cristol and Rademacher,[25] and our finding of 11.5% retention of bromine-82 label in the product Ib are in agreement. For example, Young[7] and co-workers noted diastereomer formation during a zinc debromination–rebromination sequence using vicinal, acyclic, aliphatic dibromides. House and Ro[9] detected lack of stereospecificity in the zinc debromination of the *erythro*- and *threo*-2,3-dibromobutanes. The kinetic data[25] on elimination reactions of somewhat analogous *cis*- and *trans*-cyclohexyl bromohydrin derivatives revealed significant selectivity in only one of the three derivatives studied.

The three control experiments with the tribromide IIa and Ia have ruled out any *exchange* reaction with

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(16) The transition state of such an interchange could well be such that the four-carbon methylene bridge of the cyclohexane ring would impart enough strain to prevent the interchange. An acyclic case remains to be tested.

(17) S. Winstein, D. Pressman, and W. Young, *J. Am. Chem. Soc.*, **61**, 1645 (1939).

(18) The iodide debromination reaction has been used as a mechanistic tool in an analysis of the stereochemistry of the bromination–zinc debromination sequence in certain acyclic systems; *cf.* ref. 7. For other recent work on this reaction, *cf.* J. Milders and J. Nasielski, *Bull. soc. chim. Belges*, **72**, 322 (1963), and E. Trumbull and K. Ibne-Rasa, *J. Org. Chem.*, **28**, 1907 (1963).

(19) H. L. Goering and H. H. Espy, *J. Am. Chem. Soc.*, **77**, 5023 (1955).

(20) For elimination studies on *trans*- and *cis*-bromohydrin derivatives *cf.* ref. 9 and S. J. Cristol, J. Q. Weber, and M. C. Brindell, *ibid.*, **78**, 598 (1956).

(21) P. Bender, D. L. Flowers, and H. L. Goering, *ibid.*, **77**, 3463 (1955).

(22) If appreciable reaction occurred at the monobromide site, one would expect displacement on carbon to be a competing reaction judging from the relative rates of *trans vs. cis* dehalogenation: $k_t/k_c = 11.5$[19], but displacement by iodide ion followed by *trans* elimination of the resulting iodobromide would necessarily incorporate bromine-82 in the product. This did not happen.

(23) While reaction rates were not studied in our case, a comparison of the data from ref. 19 with ours indicates a faster rate of elimination for IIa.

(24) W. Schubert, B. S. Rabinovitch, N. Larson, and V. A. Sims, *J. Am. Chem. Soc.*, **74**, 4590 (1952).

(25) *cis*- and *trans*-cyclohexylbromohydrin derivatives have been studied: S. J. Cristol and L. E. Rademacher, *ibid.*, **81**, 1600 (1959).

zinc bromide as the source of the 11.5% radioactivity in Ib. Further, it is difficult to envision any epimerization reactions of II which would *not* result in exchange of bromide. Zinc bromide has been shown to be an ineffectual catalyst for the isomerization of olefins more nucleophilic and prone to isomerization than vinyl bromide Ia.[9] The recovery of starting materials from control experiments was 80% or better.

It would appear, then, that the source of nonstereospecificity in this case and others[9,24] resides in the reaction of vicinal dibromides with zinc itself. In view of the greater stereospecificity observed in the iodide debromination of IIa than would have been predicted from the consideration of previous results,[19] the *trans*-diaxial course seemed, *a priori*, to be the much more favored pathway for the zinc debromination of IIa, even to the exclusion of a *cis* pathway. However, the zinc debromination *still* produced a significant amount of what could be described as the *cis* product, implying either a random attack by zinc on the tribromide molecule or else epimerization occurring during donation of one or two electrons by zinc to bromine in a slow first step. The mechanism of this reaction has been discussed mainly in ionic terms in the past.[9,11,22] In light of recent discoveries involving one-electron transfer processes[26] and neighboring group participation by bromine in radical substitution reactions,[27] it would appear that the mechanistic question of zinc debrominations is still open. The nonstereospecificity of the zinc reactions has generally been attributed to isomerization of a reaction intermediate.[9,24] While this may be a more likely explanation for the zinc results in this present case, a *cis* elimination cannot be excluded. In any event, additional definitive work is needed to establish the mechanism of the zinc-promoted debromination reaction.

Experimental

Vapor Phase Chromatography. All studies were made on an F and M Scientific Corporation Model 720 dual column programmed temperature gas chromatograph with a Bristol Dynamaster recorder. The column was 10% silicone gum rubber (SE-30) on 60–80 mesh Diatoport W. All studies with 2,3-dibromocyclohexene, 1-bromocyclohexene, and 1,1,2-tribromocyclohexane were carried out under the following conditions: helium pressure 30 p.s.i. and 60 ml./min., injection port temperature, 160°, column temperature, 138–145°, and detector temperature, 290°. Neat samples were injected and excellent separations were achieved.

Counting. A Nuclear Chicago Corporation Model 186 scintillation counter in combination with an NRD Instrument Co. Model L-6 well was employed. All samples were counted neat in half-dram vials.

2,3-Dibromocyclohexene. This olefin was prepared by a modification of the procedure of Sonnenberg and Winstein.[11] Solid potassium *t*-butoxide was prepared by dissolving potassium (5.73 g., 0.15 g.-atom) in 120 ml. of dry *t*-butyl alcohol followed by removal of excess alcohol and drying of the residual white solid *in vacuo* for 4 hr. at 40°.

Bromoform (35.3 g., 0.15 mole) was added dropwise to a cooled, vigorously stirred slurry of cyclopentene (10.0 g., 0.15 mole), potassium *t*-butoxide (0.15 mole), and dry pentane (65 ml.). Temperature was kept below 3° during addition, then was let rise to 25° over a 2-hr. period. The mixture was poured onto ice, and the aqueous layer was extracted with pentane (three 200-ml. portions). The pentane extract was washed with water (three 200-ml. portions), dried over anhydrous magnesium sulfate, and the pentane was removed under aspirator pressure. The residue liquid, 25.9 g., was distilled through a 2.0 × 15.0 cm. Vigreux column and gave 16.47 g. (47% based on moles of cyclopentene) of 2,3-dibromocyclohexene, b.p. 124–125°, n^{25}D 1.5754 (lit.[11] b.p. 105–106° (9.5 mm.), n^{25}D 1.5760).

1-Bromocyclohexene (Ia). To a refluxing solution of lithium aluminum hydride (3.0 g.) in tetrahydrofuran (175 ml., distilled twice from lithium aluminum hydride) was added dropwise 28.4 g. (0.12 mole) of 2,3-dibromocyclohexene in 25 ml. of tetrahydrofuran. After 64 hr. at reflux, excess hydride was destroyed and the pot was diluted with water (600 ml.). The aqueous layer was extracted with pentane (three 200-ml. portions), and the pentane extract was washed with water (three 200-ml. portions) and saturated sodium chloride solution (100 ml.) and dried over anhydrous magnesium sulfate. Following removal of pentane, distillation of the residual liquid yielded 13.5 g. of Ia (72%), b.p. 63° (20 mm.), n^{25}D 1.5110 (lit.[13] b.p. 44–46° (7 mm.), n^{25}D 1.5109). Vapor phase chromatographic analysis showed only one peak, and the compound was considered to be pure.

1,1,2-Tribromocyclohexane (Unlabeled IIa). To Ia (12.05 g., 0.08 mole) in 50 ml. chloroform was added a chilled solution of bromine (12.05 g., 0.08 mole), in 100 ml. of chloroform, portionwise over a period of 2 hr. After the solution stood at 0° for 24 hr. the chloroform was removed at aspirator pressure and the residual liquid subjected to a vacuum distillation through a 2.0 × 15.0 cm. Vigreux column. This typical procedure yielded 17.36 g. (72%) of unlabeled IIa, b.p. 55–56° (0.08 mm.), n^{25}D 1.5870, m.p. 16–17°.

Anal. Calcd. for $C_6H_9Br_3$: C, 22.46; H, 2.83; Br, 74.71. Found: C, 22.55; H, 2.86; Br, 74.80.

Radioactive Bromine-82.[28] To a solution of 3 ml. of 0.10 *M* potassium bromide and 1 ml. of 0.05 *M* potassium bromate in a 15-ml. separatory funnel was added 0.5 ml. of potassium bromide-82 solution. Following careful acidification with concentrated hydrochloric acid, radioactive bromine-82 was extracted with chloroform (three 5-ml. portions) and the chloroform extract was dried over anhydrous magnesium sulfate. This radioactive bromine-82–chloroform solution was added to nonradioactive bromine (16.0 g., 0.10 mole) in 50 ml. of chloroform in a 100.0-ml. volumetric flask and diluted to the specified volume with chloroform. Two 100-μl. aliquots of this inoculated stock solution served

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(26) G. A. Russell, E. G. Janzen, and E. T. Strom, *J. Am. Chem. Soc.*, **86**, 1807 (1964); for the analogous mechanism of Grignard formation: H. M. Walborsky and A. E. Young, *ibid.*, **86**, 3288 (1964).

(27) W. Thaler, *ibid.*, **85**, 2607 (1963); P. S. Skell and P. Readio, *ibid.*, **86**, 3334 (1964), and references cited therein.

(28) Bromide-82, a γ emitter with a half-life of 35.9 hr., is obtained as 0.15 ml. of aqueous potassium bromide with an activity of *ca.* 1 mc. per ml. from the Union Carbide Nuclear Company, Oak Ridge, Tenn., at nominal cost. The solution is conveniently diluted with 8.0 ml. of water. The bromine-82 is prepared from a 0.5-ml. aliquot of this solution. Sufficient activity for convenient counting of all radioactive compounds within a ten-day period is obtained.

as secondary standards (reduced to bromide ion in 3.0 ml. of 0.1 *M* sodium bisulfite) for the remainder of the experiment.

1,1,2-Tribromocyclohexane (IIa). IIa was prepared as previously described by the reaction of bromine (16.0 g., 0.10 mole) inoculated with bromine-82 with Ia (15.73 g., 0.09 mole) at 0° for 18 hr. which yielded IIa, 18.35 g., b.p. 55–56° (0.08 mm.), n^{25}D 1.5869. Analysis by vapor phase chromatography indicated one peak, and the compound was considered to be pure.

Debromination of IIa with Sodium Iodide. IIa (14.0 g., 0.04 mole) and sodium iodide (15.0 g., 0.10 mole) in 50 ml. of methanol were heated in a sealed tube at 110° for 18 hr. The reaction mixture was then diluted with water (1000 ml.) and treated with 21.0 g. of sodium thiosulfate in 100 ml. of water. The organic layer was separated and the aqueous layer extracted with pentane (five 200-ml. portions). The organic layer and pentane extract were combined, washed with water (three 200-ml. portions), and dried over anhydrous magnesium sulfate. Following the removal of pentane, the residual liquid was distilled through a 1.0 × 10.0 cm. Vigreux column with a variable take-off receiver yielding 2.5 g. of Ia, b.p. 57–58° (15 mm.), n^{25}D 1.5115. Vapor phase chromatographic analysis indicated one peak, and the compound was considered to be pure.

The γ activity of the vinyl bromide Ia was then measured against IIa. A sample from the distillation of the sodium iodide reaction product, 0.3037 g. (1.984 mmoles), was used for counting against Ia, 0.1872 g. (0.574 mmole), as standard. Counting was performed in a well-type container in the following sequence: (background (B), vinyl bromide (V), standard (S)), V,S,V,S,B. Each sample, including background, was counted for 5 min. at 1-min. intervals. Background readings were 316 and 318 c.p.m., average 317 c.p.m. The standard measured 161,648; 162,959; and 161,783 c.p.m., average 162,130 c.p.m. or 161,813 c.p.m. corrected for background. Vinyl bromide readings were 1164, 1152, and 1168 c.p.m., average 1161 c.p.m. or 844 c.p.m. corrected for background. Accordingly, vinyl bromide counted 425 c.p.m./mmole and the standard 140,403 c.p.m./mmole corrected for two bromine-82 atoms per molecule IIa, indicating that 0.30% bromine-82 was incorporated into the vinyl bromide in the sodium iodide debromination of IIa. The same samples counted two days later, in a lower counting range, in an identical manner gave a value of 0.31% incorporation. In view of probable weighing and counting errors of 0.3%, the value is reported as 0.3% ± 0.3%.

Debromination of IIa with Zinc. IIa (12.0 g., 0.04 mole) in 5 ml. of ethanol was added dropwise to a vigorously stirred mixture of zinc (2.5 g., 0.04 g.-atom, granular 20 mesh) in 5 ml. of ethanol over a period of 1.5 hr. The mixture was stirred for an additional 15.5 hr. at 25°, then diluted with water (200 ml.) and extracted with pentane (three 150-ml. portions). The pentane extract was washed with water (three 200-ml. portions) and saturated sodium chloride solution (100 ml.) and was dried over anhydrous magnesium sulfate. Distillation of the crude product (5.64 g.) through a 1.0 × 10.0 cm. Vigreux column with variable take-off receiver yielded 3.34 g. of Ib, b.p. 40° (8 mm.), n^{25}D 1.5114. Vapor phase chromatographic analysis indicated one peak and the compound was considered to be pure. The γ activity of the vinyl bromide was measured against IIa as standard. Different samples of both compounds were counted on three different occasions over a four-day period.

The results of a typical counting made at intermediate counting range are shown in Table I as counts per minute corrected for background. All vinyl bromide, standard, and background readings were taken for 3 min. each without appreciable time delay. The average of two background readings taken before and after the counting sequence was 310 c.p.m. The counting was performed in the following sequence: vinyl bromide, standard, vinyl bromide, standard. Accordingly, vinyl bromide samples 1 and 3 counted 20,235 and 19,997 c.p.m./mmole, respectively; tribromide samples 2 and 4 counted 175,322 and 173,708 c.p.m./mmole, respectively, corrected for 2 bromine-82 atoms per molecule of IIa. Ratios of 1:2, 1:4, 3:2, and 3:4, gave retention values of 11.54, 11.65, 11.41, and 11.51%; average 11.53%. For countings made at higher and lower counting ranges, values of 11.52 and 11.39% were obtained. A value of 11.5 ± 0.5% includes weighing and counting errors involved in the experimental procedure.

Table I[a]

Sample 1, vinyl bromide (Ib), 0.1631 g., 1.01 mm.	Sample 2, standard IIa, 0.1025 g., 0.319 mm.	Sample 3, vinyl bromide (Ib), 0.0502 g., 0.312 mm.	Sample 4, standard Ia, 0.1550 g., 0.483 mm.
20,555	112,770	6237	169,462
20,481	112,429	6290	168,417
20,408	111,637	6257	167,138
20,302	110,589	6172	166,193

[a] Counts per minute per mmole.

Bromination of Ib with Nonradioactive Bromine. Ib (0.80 g.) (product of the reaction of zinc and IIa) was diluted with 5.0 g. of Ia (nonradioactive) prepared previously. According to the procedure previously described, Ib (5.8 g., 0.04 mole) and bromine (6.0 g., 0.04 mole) in chloroform at 0° for 23 hr. gave 7.6 g. of IIb (one labeled bromine atom per molecule), b.p. 57° (0.10 mm.), n^{25}D 1.5870.

Debromination of IIb with Sodium Iodide. As previously described, 7.4 g. (0.02 mole) of IIb and 7.5 g. (0.05 mole) of sodium iodide in 25 ml. of methanol were heated in a sealed tube at 110° for 13.5 hr. and yielded 1.50 g. of Ib, b.p. 40° (8 mm.), n^{25}D 1.5120. Vapor phase chromatographic analysis indicated Ib to be pure.

A sample of Ib (0.2998 g., 1.86 mmoles) from the product of IIb with sodium iodide was counted along with the initially diluted sample of Ib (0.1123 g., 0.697 mmole) and IIb (0.1169 g., 0.354 mmole). The latter two samples served as standards. The counting was performed in sequence without appreciable time delays. Each sample was counted for 5 min. including background readings. The background average was 350 c.p.m. for three readings. The results are shown in Table II as counts per minute corrected for background.

Standard Ib counted an average 923 c.p.m./mmole, standard IIb 923 c.p.m./mmole, and the vinyl bromide

Table II[a]

Standard Ib, 0.697 mmole	Standard IIb, 0.364 mmole	Product of NaI with IIb (Ib), 1.86 mmoles
630	335	1748
650	349	1749
649	341	1744
644	318	1680

[a] Counts per minute per mmole.

product from sodium iodide with IIb 929 c.p.m./mmole. The per cent retention calculated from these averages was 100.6%. This percentage value falls within the ±1.0% weighing and counting errors of the experiment. The value, thus, is reported as 100.0 ±1.0%.

Zinc Bromide. 1,2-Dibromoethylene (10.0 g., 0.05 mole) in 10 ml. of ethanol was added dropwise to a stirred mixture of zinc (3.5 g., 0.05 g.-atom) in 10 ml. of ethanol. After 3 hr. at reflux the removal of the solvent yielded 11.0 g. of white powdery zinc bromide. Bromide determination by the Volhard method indicated the sample to be 98.7% pure.

Labeled zinc bromide was prepared by inoculation of the ethanolic zinc bromide solution with a small amount of bromide-82 concentrate. Labeled zinc bromide was reisolated as a white powder for use in exchange reactions.

Exchange of IIa with Zinc Bromide. A solution of IIa (3.21 g., 10 mmoles) and zinc bromide (2.25 g., 10 mmoles) in 4 ml. of ethanol stood at 25° for 30 hr. IIa was reisolated (2.8 g.). Vapor phase chromatographic analysis showed one peak, and the compound was considered to be pure.

Reisolated IIa (0.389 mmole) was counted against two samples of starting IIa (0.319 and 0.483 mmole) as standards. Corrected for background, 324 c.p.m., reisolated IIa measured 295,725 c.p.m./mmole, 0.319 mmole standard IIa 297,468 c.p.m./mmole and 0.483 mmole standard IIa 297,265 c.p.m./mmole, loss of bromine-82 per mole of IIa being 0.52 and 0.59% calculated for each standard sample. The average loss of bromide-82 per mole of IIa was 0.56%. In view of the ±1.4% counting and weighing errors involved in the experimental procedure, the loss of 0.56% bromine-82 label falls within those limits.

Exchange of Unlabeled IIa with Labeled Zinc Bromide. A solution of unlabeled IIa (2.70 g., 8.4 mmoles) and labeled zinc bromide (1.90 g., 8.4 mmoles) in 3 ml. of ethanol was allowed to stand at 25° for 35 hr. Unlabeled IIa (2.2 g.) was reisolated and vapor phase chromatographic analysis indicated the compound to be pure.

Corrected for the background, 338 c.p.m., reisolated unlabeled IIa (0.2245 g., 0.699 mmole) measured 112 c.p.m./mmole and standard labeled zinc bromide (0.0393 g., 0.174 mmole) 11,056 c.p.m./mmole corrected for 98.7% purity by titration analysis. This calculates to be an incorporation of 1.01% bromine-82 per mole of unlabeled IIa. Different samples counted at a later time gave an incorporation value of 0.92%. The average value of incorporation was 0.97%. Considering counting and weighing errors, a value of 0.97 ± 0.20% exchange of bromine-82 per mole of unlabeled IIa was detected.

Exchange of Ia with Labeled Zinc Bromide. Ia (0.50 g., 3.1 mmoles) and labeled zinc bromide (0.70 g., 3.1 mmoles) in 1 ml. of ethanol was allowed to stand at 25° for 24.5 hr. Vapor phase chromatographic analysis of the reisolated, distilled Ia indicated the compound to be pure.

Reisolated Ia (0.1947 g., 1.21 mmoles) was measured against labeled zinc bromide (0.0456 g., 0.202 mmole) as standard. Corrected for background, 313 c.p.m., reisolated Ia measured 52 c.p.m./mmole, and the standard zinc bromide 14,230 c.p.m./mmole; again, corrected for a purity of 98.7% by titration assay. The value for incorporation was 0.37 ± 0.09% bromine-82 per mole of vinyl bromide after considering the experimental error.

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