

(25 g.) was then added, and the mixture was subjected to steam distillation. The oil which distilled was taken up in low-boiling ligroin, the ligroin solution washed with water, and sodium carbonate solution (10%), and dried over anhydrous sodium sulfate. On distillation, there was obtained an oil (9 g.), b. p. 90–110° (12 mm.); n_D^{20} 1.4520. This material formed a 2,4-dinitrophenylhydrazone which melted at 125–126°, and did not depress the melting point of an authentic sample of the 2,4-dinitrophenylhydrazone of 2-nonenal.¹⁰

Reaction of Bromoform with Styrene.—A mixture of bromoform (156 g., 0.62 mole), redistilled styrene (15.6 g., 0.15 mole), and benzoyl peroxide (1.0 g.) was heated at 100° for four hours. Then an additional amount of benzoyl peroxide (0.8 g., total benzoyl peroxide 0.008 mole) was added and heating was continued for two hours longer. The excess bromoform was removed by distillation at reduced pressure, and a small amount of benzoic acid was removed by sublimation *in vacuo*. The residue (26.6 g.) was a thick black sirup which appeared to consist chiefly of a product containing two moles of styrene to one mole of bromoform with smaller amounts of products containing one, three and perhaps four moles of styrene per mole of bromoform.

Anal. Calcd. for $C_{17}H_{17}Br_3$: Br, 52.2; mol. wt., 460. Found: Br, 44.6; mol. wt., 507.

The sirupy reaction product (26 g.) was transferred to a small distilling flask and distilled *in vacuo*. The distillate (2.6 g.) appeared to be slightly impure phenyltribromopropane, b. p. 110–115° (0.1 mm.), n_D^{20} 1.6110.

Anal. Calcd. for $C_9H_9Br_3$: Br, 67.2. Found: Br, 65.4.

The Reaction of Carbon Tetrachloride with Octene-1 in Ultraviolet Light.—Carbon tetrachloride (182.1 g., 1.18 mole) and octene-1 (39.9 g., 0.36 mole) were mixed in a quartz reflux apparatus. The mixture was held at its boiling point and irradiated with a 500-watt Hanovia ultraviolet lamp for a period of four hours.

(10) Scanlan and Swern, *THIS JOURNAL*, **62**, 2309 (1940).

After the unchanged carbon tetrachloride and octene-1 had been removed by distillation, 1,1,1,3-tetrachlorononane (b. p. 72–75° (0.1 mm.); n_D^{20} 1.4768; 20.3 g.) distilled. A residue (3.9 g.) remained in the distilling flask.

Because yields obviously depend on intensity and duration of irradiation no percentage yield is recorded in Table I.

Summary

In photochemical or peroxide-induced reactions with olefins containing terminal double bonds, carbon tetrachloride, carbon tetrabromide, chloroform and bromoform yield addition and polymerization-addition products.

Reactions of carbon tetrachloride with octene-1, styrene, ethyl acrylate, allyl, propylene and ethylene; of carbon tetrabromide with octene-1, styrene and ethylene; of chloroform with octene-1 and allyl; and of bromoform with octene-1 and styrene are described.

For all the halides mentioned, chain reactions may be induced by the free radicals generated in the thermal decomposition of diacyl peroxides.

Carbon tetrabromide participates in chemical reactions under the influence of visible light; carbon tetrachloride requires ultraviolet light.

Reaction mechanisms have been proposed, and the determined structures of one-to-one halide-olefin addition products are consistent therewith.

Approximately equivalent ratios of halide to olefin in polymerization-addition products have been estimated.

CHICAGO, ILLINOIS

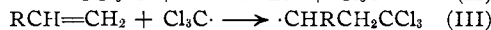
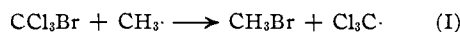
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[CONTRIBUTION FROM THE GEORGE HERBERT JONES CHEMICAL LABORATORY OF THE UNIVERSITY OF CHICAGO]

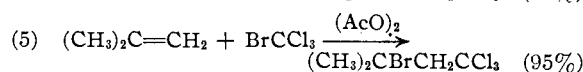
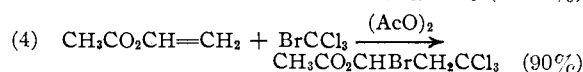
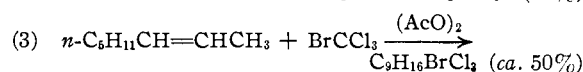
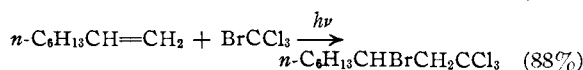
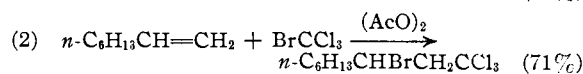
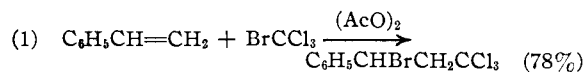
Reactions of Atoms and Free Radicals in Solution. XI. The Addition of Bromotrichloromethane to Olefins

BY M. S. KHARASCH, OTTO REINMUTH AND W. H. URRY

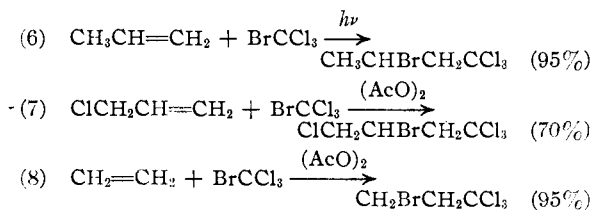
The considerations outlined in our previous paper on the addition of carbon tetrachloride, carbon tetrabromide, chloroform and bromoform to olefins,¹ suggested an investigation of the reactions of heteropolyhalides with olefins. The addition reactions of bromotrichloromethane with a number of olefins are described in the present paper. These reactions, both with regard to ease of initiation and propagation, and the nature of the products formed, resemble those of carbon tetrabromide rather than those of carbon tetrachloride. It is, therefore, a reasonable supposition that the reactions of bromotrichloromethane with olefins are initiated by reactions I and II, and are propagated by reactions III and IV.



The following additions have been effected:

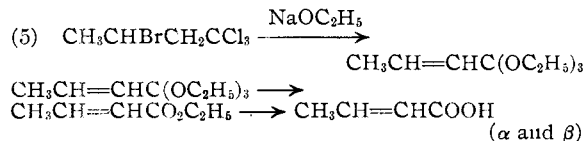
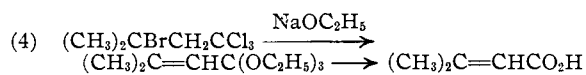
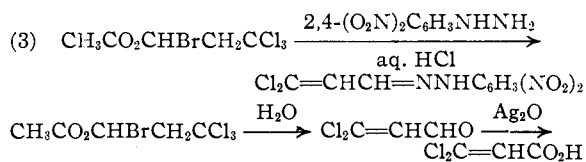
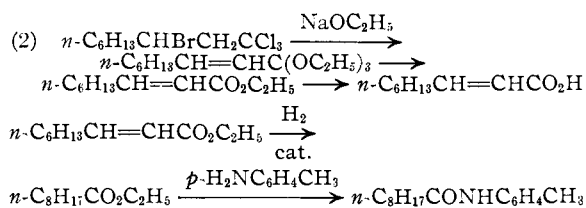
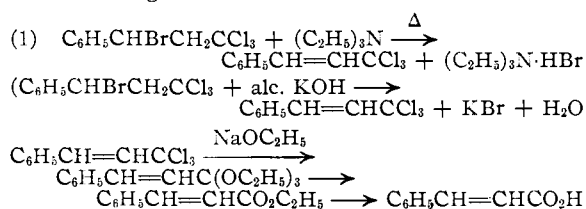


(1) Kharasch, Jensen and Urry, *THIS JOURNAL*, **69**, 1100 (1947).



Although these reactions may be carried out without any special precautions to exclude atmospheric oxygen, better results are usually obtained under an inert atmosphere, suitably nitrogen.

The structures here assigned to the addition products are in accordance with the reaction scheme (I to IV) outlined. Direct evidence for these structures was obtained by carrying out the following reactions.



A detailed account of the procedures used is contained in the experimental part.

Discussion

In addition reactions with olefins, bromotrichloromethane is for many reasons (*e. g.*, lower cost, lower molecular weight, ease of recovery, etc.) preferable to carbon tetrabromide as a reagent. Its advantages over the still cheaper carbon tetrachloride are as follows.

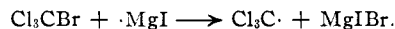
1. Where high polymers are to be avoided, bromotrichloromethane, even in low (3 to 1) molecular ratio to the olefin present gives high yields of the one-to-one addition product.

2. Bromotrichloromethane adds to olefins such as allyl chloride or octene-2.² Fair yields of the one-to-one addition product are readily obtained, whereas carbon tetrachloride adds to these olefins only in traces, if at all.

3. Bromotrichloromethane adds to styrene to give a high yield of the one-to-one addition product. With carbon tetrachloride, the competing polymerization-addition leads to high polymers containing many styrene units per halide unit. Only minute amounts of the one-to-one addition product of carbon tetrachloride and styrene are formed even though a twenty-to-one or a fifty-to-one molar ratio of the halide be used. With bromotrichloromethane high yields of the one-to-one addition product are obtained, even when the ratio of the halide to styrene is only three-to-one or four-to-one.

4. The behavior of styrene with carbon tetrachloride is characteristic of all olefins in which the free radical formed upon addition of the trichloromethyl unit (*e. g.*, $\cdot\text{CH}(\text{C}_6\text{H}_5)\text{CH}_2\text{CCl}_3$) is a very weakly electronegative radical. Thus, chlorostyrene, vinyl naphthalene, etc., behave like styrene.

5. The reaction between bromotrichloromethane and an olefin is much easier to initiate and to propagate than the corresponding reaction with carbon tetrachloride. For example, lower quantities of peroxide reagent are needed, a fact which indicates a longer chain. Furthermore, the best initiators for the addition of carbon tetrachloride are diacyl peroxide and ultraviolet light. For the reaction with bromotrichloromethane these initiators may be used, but visible light is sufficient. Even more remarkable is the fact that magnesium turnings (or still better magnesium turnings and a trace of iodine), or finely divided nickel and a trace of iodine, are excellent initiators for the addition reaction in question. Presumably such reactions are initiated by reactants of the magnesium halide type

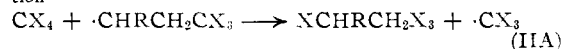


The relative yields of one-to-one halogen-olefin addition product and higher polymerization products are determined primarily by the lability of the most reactive halogen atom in the halide CX_4 or $\text{CX}_3\text{X}'$. They are also influenced to some extent by the nature of the radical R (in the olefin $\text{RCH}=\text{CH}_2$), which in turn affects the relative reactivity³ of the radical $\cdot\text{CHRCH}_2\text{CX}_3$.

When the nature of the reactants is such that there is little or negligible one-to-one addition

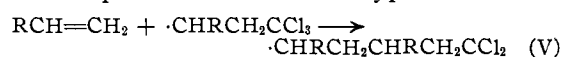
(2) The addition of bromotrichloromethane to butadiene, isoprene (and other dienes) will be discussed in a forthcoming publication by Kharasch, Nudenberg and Urry. These substances do not add carbon tetrachloride. Moreover, acetylenes add bromotrichloromethane but not carbon tetrachloride (Kharasch, Jerome and Urry).

(3) A relatively reactive free radical in the sense here intended is one which requires a relatively low energy of activation for the reaction

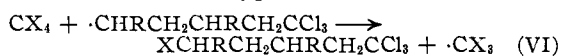


product, the influence of the radical R is further manifested in the nature of polymerization product. For example, when allyl chloride (R = CH₂Cl) is treated with a fourfold excess of carbon tetrachloride and an acyl peroxide, the major product (70–80%) consists of two molecular equivalents of allyl chloride per molecular equivalent of carbon tetrachloride. When styrene (R = C₆H₅) is similarly treated there is little product of the one-to-one or two-to-one olefin-halide type; the major product contains many molecular equivalents of styrene per molecular equivalent of carbon tetrachloride.

It is altogether possible that the influence of the radical R is exerted in two ways: (1) by activation or deactivation of the olefinic double bond with respect to reactions of the type

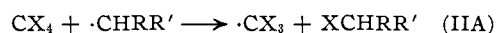


and (2) by its effect upon the reactivity of the free radical $\cdot CHRCH_2CHRCH_2CCl_3$ with respect to reactions of the type

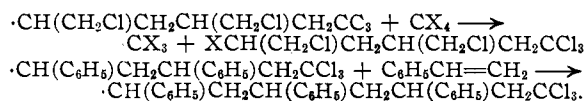


The former point is still under investigation in this Laboratory and will be discussed in a forthcoming paper.

Regarding the latter point some conclusions may be drawn from the comparison just cited. If a radical $\cdot CHRCH_2CCl_3$ be regarded as a substituted methyl radical of the type $\cdot CHRR'$, it may be inferred that, whatever, the nature of the substituent R, the substituent R' = CH₂CCl₃ is a strong deactivator⁴ of the radical with respect to the reaction



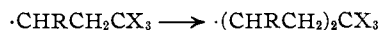
The radical $\cdot CHRCH_2CHRCH_2Cl_3$ may be similarly regarded as a substituted methyl radical of the type $\cdot CHRR''$. In the substituent R'' (*i. e.*, —CH₂CHRCH₂CCl₃) the potent trichloromethyl group is far removed from the scene of action, and the substituent as a whole differs little in effect (save sterically) from the average alkyl substituent. The reactivity of the radical $\cdot CHRR''$ with respect to the reaction IIA is therefore determined primarily by the effect of the substituent R. In the case of allyl chloride, R (*i. e.*, —CH₂Cl) must be at most only a mild deactivator of the radical. In the case of styrene, R (*i. e.*, —C₆H₅) is obviously a relatively effective deactivator. The consequence is that the reactions tend toward divergent courses.



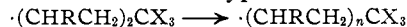
It is noteworthy that in reactions of this type the "dimeric" polymerization-addition product is

(4) That is it tends to increase the energy of activation of reaction IIA.

the only one that may be uniquely favored, for it is only in the transition

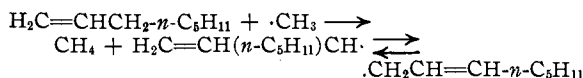


that a significant increase in radical reactivity (with respect to reaction IIA) may occur. Subsequent transitions of the type

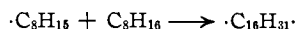


can have little or no effect (other than steric) on radical reactivity.

This, however, is not necessarily the case in *all* types of polymerization reactions. As yet unpublished data obtained in this Laboratory indicate that in the peroxide-induced polymerization of octene-1 (in the absence of any co-additive agent) the trimeric form is uniquely favored. This polymerization is presumably initiated by the reaction



and continued by some reaction of the type



It seems desirable to defer detailed discussion of this polymerization until the constitution of the dimer and the mechanism of chain termination have been more fully investigated.

Experimental

Peroxide-induced Addition of Bromotrichloromethane to Styrene.—A solution of 12 g. of styrene and 2.3 g. of acetyl peroxide in 100 g. of bromotrichloromethane was warmed at 60–70° for four hours. Seventy-eight grams of bromotrichloromethane (b. p. 103–104°) was recovered by distillation at atmospheric pressure through a 10-inch Vigreux column. Further distillation at reduced pressure (92° (0.2 mm.)) yielded 27 g. (78%) of a colorless oil which quickly solidified to a white crystalline mass. The high-boiling still residue (polymerization-addition product) amounted to 5.8 g. The solid material, after one recrystallization from methanol, melted at 54.5–55.0°, and gave a halogen analysis consistent with 1,1,1-trichloro-3-bromo-3-phenylpropane.

Anal. Calcd. for C₉H₈Cl₃Br: Ag equiv., 75.5. Found: Ag equiv., 75.4.

Identification of Bromotrichloromethane-Styrene Addition Product. (1,1,1-Trichloro-3-bromo-3-phenylpropane).—(a) A solution of 27 g. of the addition product in 36 g. of triethylamine was heated under reflux for ten hours. The reaction mixture was chilled and the crude crystalline precipitate (17 g.) was removed by filtration. The white crystals obtained upon recrystallization of the precipitate from water (with Norit) gave the correct melting point (223–225°) and halogen analysis for triethylamine hydrobromide.

Anal. Calcd. for C₉H₁₀NBr: Ag equiv., 182. Found: Ag equiv., 174.

The filtrate remaining after removal of the crystalline precipitate from the reaction mixture was diluted with about ten volumes of 10% sulfuric acid and extracted with ether. The ether extract was twice washed with three volumes of 10% sulfuric acid, once with three volumes of water, and once with three volumes of 5% potassium carbonate solution, and was then dried over anhydrous potassium carbonate. After removal of the ether at atmospheric pressure, two distillations of the residual oil at reduced pressure yielded a 10-g. fraction, b. p. 93–95° (0.3 mm.; *n*_D²⁰ 1.5731) which gave a halogen analysis consistent with 1-phenyl-3,3,3-trichloropropene.

Anal. Calcd. for $C_9H_7Cl_3$: Ag equiv., 48.1. Found: Ag equiv., 47.6.

(b) A 15-g. portion of bromotrichloromethane-styrene addition product was refluxed for ten hours in an ethanol-sodium ethoxide solution prepared from 6 g. of sodium and 200 ml. of ethanol. After removal of the precipitated salts by filtration, 10 g. of potassium hydroxide and 25 ml. of water were added to the solution, and reflux was continued for four hours. Ethanol was removed by low-pressure distillation; the residue was diluted with 200 ml. of water and freed of water-insoluble material by extraction with ether. Acidification of the aqueous solution precipitated white crystals which, after one recrystallization from 95% ethanol melted at 133°. A mixture of these crystals with an authentic specimen of cinnamic acid melted at 132–133°.

Peroxide-induced Addition of Bromotrichloromethane to Octene-1.—A solution of 27.9 g. of octene-1 and 2.0 g. of acetyl peroxide in 116.7 g. of bromotrichloromethane was warmed at 60–70° for four hours. After distillation of excess polyhalide, further distillation at reduced pressure yielded 55 g. (77%) of a colorless oil (b. p. 99–102° (0.6 mm.); n_D^{20} 1.4943); the still residue was estimated at less than 0.5 g. The product gave a halogen analysis consistent with 1,1,1-trichloro-3-bromononane.

Anal. Calcd. for $C_9H_{15}BrCl_3$: Ag equiv., 77.7. Found: Ag equiv., 78.6.

Photochemical Addition of Bromotrichloromethane to Octene-1.—A solution of 33.7 g. of octene-1 in 173.4 g. of bromotrichloromethane was maintained at 80–90° in an oil-bath and internally illuminated with a mercury vapor-neon fluorescent coil for five hours. Distillation of the reaction mixture yielded 79.9 g. (88%) of a product identical in properties (b. p. 99–100° (0.6 mm.); n_D^{20} 1.4943) with that obtained from the peroxide-induced reaction.

Identification of Bromotrichloromethane-1-octene Addition Product (1,1,1-Trichloro-3-bromononane).—Addition of 20.6 g. of bromotrichloromethane-octene-1 product to an ethanol-sodium ethoxide (15 g. sodium, 250 ml. ethanol) solution initiated a vigorous reaction which was completed by a ten-hour reflux. The reaction mixture was chilled, and freed of precipitated salts by filtration. The filtrate was made acid to litmus with acetic acid, diluted with 250 ml. of water, and steam-distilled. The steam distillate was extracted with ligroin (b. p. 35°), and the ligroin solution was washed successively with 10% aqueous sodium carbonate and water and dried over anhydrous sodium sulfate. Atmospheric pressure distillation of the ligroin and low-pressure distillation of the residue yielded 10.5 g. of an oil (b. p. 60–75° (0.3 mm.)) of which test portions dissolved in boiling 10% sodium hydroxide solution and gave a positive unsaturation test with bromine-carbon tetrachloride solution.

The remainder of the unsaturated ester so obtained was dissolved in acetic acid and reduced in the presence of Adams catalyst under 1.2 atmospheres of hydrogen. Distillation of the filtered hydrogenation solution yielded 8.5 g. of an oil, b. p. 60–70° (0.3 mm.).

A 3-g. portion of the crude saturated ester so obtained was converted to the corresponding *p*-toluidide by the procedure of Koelsch and Tenenbaum.⁵ Upon removal of oily impurities by steam distillation there remained 1.5 g. of crystalline toluidide which, after two recrystallizations from 80% ethanol, melted at 83–84°. The melting point of its mixture with the authentic toluidide of nonanoic acid was 82–83°.

Peroxide-induced Addition of Bromotrichloromethane to Octene-2.—A solution of 56 g. of octene-2 (b. p. 125.0–125.5°; n_D^{20} 1.4146) and 0.8 g. of acetyl peroxide in 200 g. of bromotrichloromethane was warmed at 80–90° for three and one-half hours. After distillation of excess polyhalide, further distillation at reduced pressure yielded, in addition to some recovered octene, 64.6 g. of a colorless oil (b. p. 70–80° (0.3–0.5 mm.)), n_D^{20} 1.4970. The product gave a halogen analysis consistent with addition in a

1:1 molecular ratio. The high-boiling residue was negligible.

Anal. Calcd. for $C_9H_{15}BrCl_3$: Ag equiv., 77.7. Found: Ag equiv., 78.2.

Peroxide-induced Addition of Bromotrichloromethane to Vinyl Acetate.—A solution of 22 g. of vinyl acetate and 1.5 g. of acetyl peroxide in 106 g. of bromotrichloromethane was warmed to 50–60° for three hours. After removal of 64.7 g. of excess bromotrichloromethane (b. p. 103–104°), low-pressure distillation yielded 56.3 g. (89.6%) of a colorless oil (b. p. 55–60° (0.5 mm.); n_D^{20} 1.4969) which gave a halogen analysis consistent with 1-bromo-3,3,3-trichloropropyl acetate.

Anal. Calcd. for $C_6H_9O_2BrCl_3$: Ag equiv., 71.1. Found: Ag equiv., 70.6.

Identification of Bromotrichloromethane-Vinyl Acetate Addition Product. (1-Bromo-3,3,3-trichloropropyl Acetate).—A 10-g. portion of the addition product was combined with 100 ml. of 5% sulfuric acid, and the mixture was steam-distilled. The oily lower layer of the steam distillate was separated with the aid of ether, and the ether solution was successively washed with water, 5% aqueous sodium bicarbonate solution and water, and was dried over Drierite. Distillation yielded a colorless oil (b. p. 85° (35 mm.)) which gave a chlorine analysis consistent with β,β -dichloroacrolein.

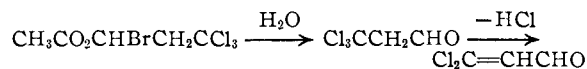
Anal. Calcd. for $C_5H_7OCl_2$: Cl, 56.9. Found: Cl, 56.4.

This aldehydic product reduced Benedict solution and formed a 2,4-dinitrophenylhydrazone melting at 164–165°.

Anal. Calcd. for $C_6H_8O_4N_4Cl_2$: N, 18.4; Cl, 23.3. Found: N, 17.9; Cl, 22.8.

An identical hydrazone (m. p. and mixture m. p.) was obtained by treating the original addition product with 2,4-dinitrophenylhydrazine in ethanolic solution in the presence of a few drops of sulfuric acid.

It is of interest that all attempts to hydrolyze the addition product resulted in simultaneous dehydrochlorination; we were unable to isolate trichloropropionaldehyde.



Upon oxidation with silver oxide, this aldehyde yielded β,β -dichloroacrylic acid. Details of this experiment will be included in a forthcoming publication.

Peroxide-induced Addition of Bromotrichloromethane to *i*-Butylene.—A solution of 2.3 g. of acetyl peroxide in 126.2 g. of bromotrichloromethane was placed in the bomb of a Parr hydrogenation apparatus. The apparatus was swept with isobutylene and the bomb was brought under a gage pressure of about 40 lb. of *i*-butylene. Complete solution of the gas (as evidenced by the drop in gage pressure to zero) took place upon shaking. The bomb and its contents were then slowly warmed by means of an electrical heating jacket to 60° at which point a gage pressure of 15 lb. had been reached. Reaction began suddenly with a drop of gage pressure to zero and a rise of temperature. The temperature was allowed to drop to 90° and was thereafter maintained at or near that point by intermittent admission of isobutylene to the bomb. When the heat of reaction was no longer sufficient to maintain the temperature of the bomb, external heating was again applied, and the bomb was maintained for three hours at a temperature of 80° under an isobutylene gage pressure of 25 lb.

The small amount of unchanged polyhalide was removed from the reaction mixture by distillation; the remainder of the bomb content distilled at 76–77° under 10 mm. pressure to yield 134 g. of colorless oil, n_D^{20} 1.5108.

Anal. Calcd. for $C_6H_8BrCl_3$: Ag equiv., 63.8. Found: Ag equiv., 63.8.

Identification of Bromotrichloromethane-Isobutylene Addition Product. (1,1,1-Trichloro-3-bromo-3-methylbutane).—A 65.1-g. portion of the addition product was

(5) Koelsch and Tenenbaum, *THIS JOURNAL*, **55**, 3049 (1933).

added to an ethanol-sodium ethoxide (34.5 g. sodium, 350 ml. ethanol) solution. The vigorous initial reaction was continued under ten hours reflux. Precipitated salts were then removed, 20 g. of potassium hydroxide in 35 ml. of water was added to the solution, and reflux was continued for six hours. Ethanol was removed from the saponification solution by low-pressure distillation; the residual solution was diluted with 200 ml. of water and acidified with dilute hydrochloric acid. The resultant crystalline precipitate (18 g.), after two recrystallizations from water, melted at 69–70°. Its mixture, with an authentic specimen of β,β -dimethylacrylic acid showed no change in melting point.

Photochemical Addition of Bromotrichloromethane to Propylene.—Bromotrichloromethane (352.5 g.) was externally cooled by an ice-bath and internally irradiated by a mercury vapor-neon fluorescent tube for twenty-four hours while propylene was slowly admitted through a gas-inlet tube. Distillation of the reaction solution yielded 185.9 g. of unchanged polyhalide and 157.8 g. of a colorless oil (b. p. 82° (20 mm.); n_D^{20} 1.5072), which gave a halogen analysis consistent with 1,1,1-trichloro-3-bromobutane.

Anal. Calcd. for $C_4H_5BrCl_3$: Ag equiv., 60.1. Found: Ag equiv., 59.7.

Identification of Bromotrichloromethane-Propylene Addition Product (1,1,1-Trichloro-3-bromobutane).—The bromotrichloromethane-propylene addition product (71.0 g., 0.295 mole) was dropped slowly into a vigorously stirred ethanol-sodium ethoxide solution (45 g. sodium; 350 ml. absolute ethanol). After the vigorous initial reaction, the mixture was heated under reflux for ten hours. The cooled mixture was freed of precipitated salts (80.2 g.) by filtration, and the filtrate was combined with a solution of 30 g. of potassium hydroxide in 75 ml. of water and was heated under reflux for six hours.

The mixture was then subjected to steam distillation, and the distillate was extracted with ligroin (35°). The extract was washed with water and dried over sodium sulfate. After removal of the ligroin, a 10.5 g. fraction (b. p. 48–54° (45 mm.), n_D^{20} 1.4260) was isolated by fractional distillation.

This material, presumably a mixture of ethyl crotonate and ethyl isocrotonate, was converted to a mixture of the corresponding *p*-toluidides by the method of Koelsch.⁶ After two recrystallizations from benzene the resultant material melted at 75–90°. After four recrystallizations it melted at 131–132° and did not depress the melting point of an authentic specimen of the *p*-toluidide of crotonic acid.

The aqueous residue from the steam distillation was acidified with sulfuric acid and was subjected to continuous ether extraction. The ether extract yielded 2 g. of crude crotonic acid, which, after two crystallizations from ligroin, melted at 71–72° and did not depress the melting point of an authentic specimen.

Peroxide-induced Addition of Bromotrichloromethane to Ethylene.—A solution of 1.54 g. acetyl peroxide in 134 g. of bromotrichloromethane was treated with ethylene in a Parr bomb apparatus in a manner similar to that described for the isobutylene reaction. After removal of unchanged polyhalide, distillation under 104 mm. pressure yielded 73.4 g. of pure product (b. p. 113.5–114° (104 mm.); n_D^{20} 1.5127) with ca. 0.5 g. of high-boiling still residue remaining. The product gave the correct halogen analysis for a 1:1 addition product.

Anal. Calcd. for $C_3H_4BrCl_3$: Ag equiv., 56.6. Found: Ag equiv., 57.0.

Identical results were obtained when the reaction was initiated by benzoyl peroxide.

In view of the highly improbable validity of any other formulation, the authors conclude that the bromotrichloromethane-ethylene addition product is 1,1,1-trichloro-2-bromopropane.

Peroxide-induced Addition of Bromotrichloromethane to Allyl Chloride.—A solution of 20 g. of allyl chloride and

2 g. of acetyl peroxide in 200 g. of bromotrichloromethane was warmed on a steam-bath for six hours. Freed of excess polyhalide, the reaction mixture yielded a 49.7 g. constant-boiling fraction (b. p. 59–60° (0.6 mm.), n_D^{20} 1.5337) which gave the correct halogen analysis for a 1:1 addition product.

Anal. Calcd. for $C_4H_5BrCl_3$: Ag equiv., 55.0. Found: Ag equiv., 55.3.

In consideration of the previously known orientation characteristics of atomic and free radical addition reactions, and of the evidences of structure reported for other 1-alkene-bromotrichloromethane addition products, the authors conclude that the bromotrichloromethane-allyl chloride addition product is probably 1,1,1,4-tetrachloro-3-bromobutane.

Peroxide-induced Addition of Carbon Tetrachloride to Allyl Chloride.—A solution of 25.5 g. (0.33 mole) of allyl chloride and 1.86 g. (0.16 mole) of acetyl peroxide in 220 g. (1.43 mole) of carbon tetrachloride was heated for six hours under a pressure of approximately 920 mm. of mercury. Preliminary distillation of the reaction mixture recovered 197 g. (1.28 mole) of carbon tetrachloride; no unchanged allyl chloride was detected.

Two successive fractionations under reduced pressure separated the reaction product into three major portions: (1) 4.8 g. of material, which, judging by refractive indices, boiling points, and chlorine analyses of the fractions consisted of a mixture of two-to-one with somewhat less one-to-one addition product; (2) 18.2 g. of substantially pure two-to-one addition product; (3) 13.7 g. of a mixture of two-to-one with three-to-one and probably some higher polymerization-addition products.

The major fraction of portion 2 boiled at 90–95° (0.4 mm.), n_D^{20} 1.5209.

Anal. Calcd. for $C_7H_{10}Cl_6$: Cl, 69.4; mol. wt., 307. Found: Cl, 69.5; mol. wt., 290.

The amounts of allyl chloride and carbon tetrachloride consumed in the reaction were in the molecular ratio 2.2:1. From the chlorine analyses of the several fractions, it is estimated that the one-to-one, the two-to-one, and the higher polymerization products are formed in the approximate ratio 1:8:4.

Bromotrichloromethane-Olefin Additions Induced by Metals and Traces of Iodine.—Two grams of magnesium turnings and a small crystal of iodine were immersed in a solution of 13 g. of styrene in 100 g. of bromotrichloromethane, and the whole was warmed on a steam-bath for 5.5 hr. Fractional distillation yielded 18.6 g. of crude product, which, after recrystallization, was identified by melting point and mixture melting point as 1,1,1-trichloro-3-bromo-3-phenylpropane.

Analogous results were obtained under similar conditions with octene-1 (14 g.), bromotrichloromethane (100 g.), magnesium turnings (2 g.) and iodine (trace) and also with octene-1 (14 g.), bromotrichloromethane (100 g.), Raney nickel (ca. 0.1 g.) and iodine (trace).

With these relatively slow reactions it is particularly desirable (though not imperative) to operate in an inert atmosphere.

Summary

In photochemical or peroxide-induced reactions with 1-alkene derivatives, bromotrichloromethane closely resembles carbon tetrabromide (rather than carbon tetrachloride) in its behavior.

Under the conditions described, such reactions give rise to good yields (70–90%) of 1:1 olefin-polyhalide addition products.

On the basis of theoretical considerations, supplemented by experimental evidences of structure, it is concluded that the addition products of bromotrichloromethane with 1-alkene derivatives studied are as follows: styrene, 1,1,1-trichloro-3-

(6) Koelsch and Tenenbaum, *THIS JOURNAL*, **55**, 3049 (1933).

bromo-3-phenylpropane; octene-1, 1,1,1-trichloro-3-bromononane; vinyl acetate, 1-bromo-3,3,3-trichloropropyl acetate; isobutylene 1,1,1-trichloro-3-bromo-3-methylbutane; propylene, 1,1,1-trichloro-3-bromobutane. It is assumed that

the ethylene addition product is 1,1,1-trichloro-2-bromopropane. It is regarded as highly probable that the allyl chloride addition product is 1,1,1,4-tetrachloro-3-bromobutane.

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The Synthesis of Organic Compounds Labelled with Isotopic Carbon¹

BY WARWICK SAKAMI,² WILLIAM E. EVANS AND SAMUEL GURIN

The use of isotopes of carbon such as C¹³ and C¹⁴ for biological studies is limited by the present availability of relatively small quantities of isotope. Another difficulty arises from the fact that the synthesis of organic compounds labelled with isotopic carbon may frequently involve condensations which give low yields. In order to conserve isotope we have devised new or modified synthetic methods for the preparation of such compounds on a small scale. To study the metabolism of acetate,^{3a,b,c} acetoacetate,^{3a,b,c} pyruvate and glycine, the preparation of these substances from isotopic cyanide⁴ and methane⁵ was investigated.

The synthesis of carboxyl-labelled sodium acetate (I) from isotopic carbon dioxide and cyanide has been reported by Olsen, Hemingway and Nier⁶ and Weinhouse, Medes and Floyd,⁷ respectively. By trapping carbon dioxide in a large evacuated bulb (equipped with a dropping funnel and reflux condenser for preparing Grignard reagent) significant losses of carbon dioxide were avoided during the reaction. Acetic acid was isolated in yields of approximately 90% while only 5% of the original carbon dioxide failed to react and could be recovered.

For the preparation of ethyl acetoacetate labelled with C¹³ in the carbonyl and carboxyl positions, sodium acetate labelled in the carboxyl group was converted in excellent yields to ethyl acetate by refluxing with diethyl sulfate followed by subsequent distillation of the ethyl acetate. The procedure of Hudson, Dick and Hauser⁸ was employed to obtain ethyl acetoacetate in yields of 26%. Thirty-five per cent. of the initial sodium acetate was recovered. The yield based on the

sodium acetate consumed was 40%. Sodium acetoacetate (II) was obtained by hydrolysis with alkali in 91% yield (based on the ethyl acetoacetate used).

Sodium acetoacetate (III) labelled in the carbonyl position only was prepared by a modification of the Röttinger and Wenzel reaction.⁹ The procedure as originally described by these authors gave rise to non-isotopic acetoacetate when the Grignard reagent prepared from ethyl bromoacetate was condensed with isotopic methyl acetate. When the preparation of the Grignard reagent was carried out in the presence of isotopic methyl acetate, however, the resulting ethyl acetoacetate was found to contain C¹³ located solely in the carbonyl position.

For the preparation of sodium acetoacetate (IV) containing C¹³ in the carboxyl group, isotopic ethyl bromoacetate was synthesized in 86% yield from carboxyl-labelled sodium acetate by adapting the method of Auwers and Bernhardt.¹⁰ The Grignard reaction was then carried out with non-isotopic methyl acetate as above described. Both samples of ethyl acetoacetate, after conversion to sodium acetoacetate, were degraded to carbon dioxide and acetone by standard procedures. Isotope analyses were performed on these materials to determine the location of the C¹³.

Glycine (V) containing C¹³ in the carboxyl position was synthesized in two ways. By condensation of isotopic ethyl bromoacetate with potassium phthalimide followed by the hydrolytic procedure described by Schoenheimer and Ratner,¹¹ glycine was obtained in 69% yield. The over-all yield from barium carbonate was 55%. Olsen, Hemingway and Nier⁶ have reported the synthesis of isotopic glycine from methane by way of acetic acid, acetyl chloride, bromoacetyl chloride and bromoacetic acid. The over-all yield was 34% (recalculated) based on the methane used.

A better synthesis of glycine involving condensation of N-chloromethylphthalimide (A) with isotopic sodium cyanide was developed. Starting

(1) Taken in part from report IB-40 issued by the Isotopes Branch, Research Division, Manhattan District.

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(3) (a) Buchanan, Sakami, Gurin and Wilson, *J. Biol. Chem.*, **157**, 747 (1945); (b) Buchanan, Sakami, Gurin and Wilson, *ibid.*, **159**, 695 (1945); (c) Buchanan, Sakami, Gurin and Wilson, *Federation Proc.*, **5**, 126 (1946).

(4) The isotopic cyanide was generously supplied by Dr. H. C. Urey.

(5) Separated by thermal diffusion.

(6) Olsen, Hemingway and Nier, *J. Biol. Chem.*, **148**, 611 (1943).

(7) Weinhouse, Medes and Floyd, *ibid.*, **158**, 411 (1945).

(8) Hudson, Dick and Hauser, *THIS JOURNAL*, **60**, 1960 (1938).

(9) Röttinger and Wenzel, *Monatsh.*, **34**, 1867 (1913).

(10) Auwers and Bernhardt, *Ber.*, **24**, 2219 (1891).

(11) Schoenheimer and Ratner, *J. Biol. Chem.*, **127**, 301 (1939).