Work continues in these laboratories both on further syntheses of cubically symmetric molecules and, now more important, on the chemical reactions of such systems.

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RECEIVED JANUARY 30, 1964

Studies in Organophosphorus Chemistry. I.
Conversion of Alcohols and Phenols to Halides by Tertiary Phosphine Dihalides

Sir:

We wish to report the preparation of a variety of alkyl and aryl halides in high yields using phosphorus reagents of the type R_3PX_2.[1,2] The method is outlined in eq. 1.

$$R_3P: + X_2 \xrightarrow{} R_3PX_2 \xrightarrow{R'OH} R_3PO + HX + R'X \quad (1)$$
$$R = C_6H_5 \text{ or } n\text{-}C_4H_9; \quad X = Br, Cl, I \quad R'; = \text{alkyl or aryl}$$
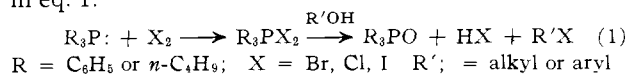
Our interest in these reagents was stimulated by the consideration that only two replaceable groups are necessary *and desirable* in reactions of compounds of the PX_5-type with alcohols.

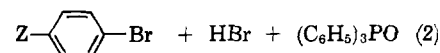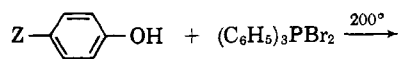Table I and eq. 2 give some indication of the scope of the reaction.

TABLE I

Alcohol	$(C_6H_5)_3PBr_2$ % yield of RBr[a]	$(n\text{-Bu})_3PBr_2$ % yield of RBr[a]	$(C_6H_5)_3PCl_2$ % yield of RCl[a]
n-Butyl	91	93	$\sim$99[b]
Isobutyl	89		
Neopentyl	79	91	92
2-Butyl	90	89	
2-Octyl	86		
2-Pentyl	$\sim$99[b,c]	$\sim$99[b,c]	
3-Pentyl	$\sim$99[b,c]	$\sim$99[b,c]	
Cyclopentyl	83	84	
Cyclohexyl	88	45 (41% olefin)[e]	$\sim$99[b]
α-Phenethyl	79		
Ethyl lactate	75		
t-Butyl	49 (25% side product)[d,e]		90[b] (10% olefin)

[a] These are yields of isolated products unless otherwise indicated. Gas chromatographic analyses of crude reaction mixtures showed no side products except as indicated. [b] Gas chromatographic analysis only. [c] The isomeric bromides were separated on a 20-ft. Carbowax column. No isomer contamination was found (<1% would be detectable). [d] Isobutylene or its dibromide was isolated depending on whether R_3PBr_2 was preformed or generated *in situ*. [e] The alkyl halide was found to eliminate under reaction conditions.

(1) These reagents do not appear to have been exploited. For a few examples see ref. 2b,c. Landauer, Rydon, and co-workers have developed a related series of reagents, $(C_6H_5O)_3PRX$, where X = halogen and R = alkyl, H, or halogen.[2d,e] These appear to be useful reagents for the preparation of many alkyl and aryl halides. For descriptions of preparations and properties of R_3PX_2 see ref. 2f, 2g, and citations therein.

(2) (a) F. Fleissner, *Chem. Ber.*, **13**, 1665 (1880); (b) L. Horner, H. Oediger, and H. Hoffmann, *Ann.*, **626**, 26 (1959); (c) H. Hoffmann, L. Horner, H. G. Wippel, and D. Michael, *Chem. Ber.*, **95**, 523 (1962); (d) S. R. Landauer and H. N. Rydon, *Chem. Ind.* (London), 313 (1951); *J. Chem. Soc.*, 2224 (1953); D. G. Coe, S. R. Landauer, and H. N. Rydon, *ibid.*, 2281 (1954); (e) D. G. Coe, H. N. Rydon, and B. L. Tonge, *ibid.*, 323 (1957); (f) V. K. Issleib and W. Seidel, *Z. anorg. allgem. Chem.*, **288**, 201 (1956); (g) G. M. Kosolapoff, "Organophosphorus Compounds," John Wiley and Sons, Inc., New York, N. Y., 1950, p. 73.

$$Z\text{—}\underset{}{\bigcirc}\text{—OH} + (C_6H_5)_3PBr_2 \xrightarrow{200°}$$

$$Z\text{—}\underset{}{\bigcirc}\text{—Br} + HBr + (C_6H_5)_3PO \quad (2)$$

$$Z = H, 92\%; \quad Cl, 90\%; \quad NO_2, 60\%; \quad CH_3O, 59\%$$

An important characteristic of these reagents is their tendency to induce substitution without elimination or rearrangement. The cyclic halide preparations best illustrate the former point.[3] The conversions of secondary pentyl and neopentyl alcohols to halides without rearrangement illustrate the latter.[4] Phenols are converted at elevated temperatures without position isomers being formed.[5]

The stoichiometry shown in eq. 1 was confirmed for n-butyl bromide formation. Triphenylphosphine oxide was isolated in 92% yield and tributylphosphine oxide hydrobromide obtained in 95% yield.[6] The HBr was determined titrimetrically.

Though results reported here are for chlorides and bromides, the method may be used for iodides as well.[7] Dimethylformamide (DMF) or acetonitrile were the most satisfactory solvents.

n-Butyl Bromide.—Dry n-butyl alcohol (9.2 ml., 0.1 mole) was mixed with 28 g. (0.107 mole) of dry distilled triphenylphosphine[8] in 100 ml. of dry DMF in a nitrogen atmosphere. Baker "purified" bromine was added over a 15-min. period while flask temperature was maintained below 55°. The addition was stopped when 2 drops persisted in giving the solution an orange tint. All volatile material was then removed by distillation at 5 mm. into a receiver cooled in a Dry Ice bath. Cold water (500 ml.) was added and 9.8 g. (91%) of n-butyl bromide separated. It was carefully removed and dried and gave b.p. 100.5–102.2° and $n^{29}D$ 1.436 (lit.[9] b.p. 100.4–100.6°, $n^{20}D$ 1.43784). The product showed one peak in the gas chromatography, which was identical in retention time with that of a reference sample of n-butyl bromide.

Neopentyl Bromide.—The reaction was performed as above employing 22.0 ml. (0.088 mole) of distilled tributylphosphine,[8] 6.95 g. (0.079 mole) of dry neopentyl alcohol, and 4.1 ml. (0.082 mole) of bromine in 75 ml. of DMF.

The mixture was distilled at 2 mm. until no more material came over below 84°. Dilution of the distillate with cold water gave 10.89 g. (91%) of neopentyl bromide, $n^{31.5}D$ 1.4310 (lit.[10] b.p. 104.8 at 732 mm., $n^{20}D$ 1.4370). It showed a single peak in gas chromatography with retention time identical with that of an authentic sample. It gave no precipitate with alcoholic silver nitrate.

Neopentyl Chloride.—Triphenylphosphine dichloride was prepared by chlorination of 10.0 g. (0.037 mole) of

(3) P. Carré and D. Libermann, *Bull. soc. chim. France*, [4] **53**, 1051 (1933); C. E. Wood and M. A. Comley, *J. Chem. Soc.*, **125**, 2636 (1925); E. P. Kohler and M. C. Burnley, *Am. Chem. J.*, **43**, 413 (1910).

(4) (a) F. C. Whitmore and H. S. Rothrock, *J. Am. Chem. Soc.*, **54**, 3431 (1932); (b) L. H. Sommers, H. D. Blankman, and D. C. Miller, *ibid.*, **73**, 3542 (1951); (c) the preparations of 2- and 3-pentyl bromides from the corresponding alcohols reported here appear to be the first direct conversions in this series without isomerization, *cf.* H. Pines, A. Rudin, and V. N. Ipatieff, *J. Am. Chem. Soc.*, **74**, 4063 (1952).

(5) (a) Similar transformations have been described using $(C_6H_5)_3PCl_2$[2c] and $(C_6H_5O)_3PCl_2$,[2e] the latter being limited to negatively substituted phenols.[2e] (b) This reaction was not attempted using $(n\text{-Bu})_3PX_2$ since at high temperatures a similar substance is reported to decompose to alkyl halide and halophosphine [J. N. Collie and G. N. White, *J. Chem. Soc.*, **107**, 367 (1915)].

(6) This substance analyzed for $(n\text{-Bu})_3PO\cdot 2/_3HBr$.

(7) R. L. Hershkowitz, unpublished results.

(8) Metal and Thermit Co., 100 Park Avenue, New York, N. Y.

(9) C. P. Smyth and E. W. Engel, *J. Am. Chem. Soc.*, **51**, 2651 (1929).

(10) F. C. Whitmore, E. L. Whittle, and B. R. Harriman, *ibid.*, **61**, 1585 (1939).

triphenylphosphine in carbon tetrachloride followed by exhaustive evaporation of the solvent. Fifty ml. of DMF and 1.6 g. (0.018 mole) of neopentyl alcohol were added and the mixture refluxed for 1 hr. The work-up above gave 2.5 g. (92%) of neopentyl chloride, which gave no precipitate with alcoholic silver nitrate; n.m.r., δ (TMS) 1.03 and 3.36 p.p.m. (sharp singlets).

p-Chlorobromobenzene.—Triphenylphosphine dibromide was prepared from 30 g. (0.11 mole) of triphenylphosphine in 100 ml. of acetonitrile. The solvent was evaporated, 10.3 g. (0.08 mole) of *p*-chlorophenol added, and the mixture heated at 200° until no more HBr was evolved (*ca.* 2 hr.). Steam distillation yielded 13.8 g. (90%) of *p*-chlorobromobenzene, which showed a single peak in its gas chromatogram and gave m.p. 64.8–65.5° (uncor.) (lit.[11] m.p. 66°) after crystallization from benzene.

The mechanism of this reaction is under investigation, as well as studies to define its scope, limitations, and stereochemistry.

Acknowledgment.—This research was supported in part by Public Health Service Research Grant GM-08956 from the National Institute of General Medical Sciences.

(11) M. L. Sherrill, *J. Am. Chem. Soc.*, **46**, 2756 (1924).

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Stereochemistry of "No-mechanism" Reactions : Transfer of Asymmetry in the Reaction of Olefins with Dienophiles

Sir:

One of the simplest reactions between organic molecules (though paradoxically ignored in nearly all organic texts) is the thermal addition of olefins to dienophiles. Discovered during the 1930's, the reaction was first investigated thoroughly by Alder and his students[1] and classified as an "indirect substitutive addition"

$$R_1R_2CH-CH=CH_2 + X-CH=CH-Y \xrightarrow{\Delta}$$

$$R_1R_2C=CH-CH_2-CHX-CH_2Y$$
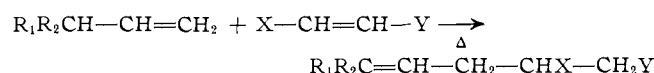
Like the Diels–Alder addition of dienes to dienophiles, to which it bears a formal resemblance, the reaction has presented the same nearly inscrutable facade to efforts to deduce a detailed mechanism. Early attempts to ascribe to the reaction free-radical[2] or ionic[3] character have been abandoned in favor of a concerted, four-center, cyclic mechanism (Fig. 1), first suggested
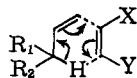

Figure 1.

by Koch[4] and by Arnold and Dowdall.[5] Consequently this addition appears to fall into the category of thermal reorganization processes, aptly described[6] as "no-mechanism" reactions.

(1) K. Alder, F. Pascher, and A. Schmitz, *Ber.*, **76**, 27 (1943); K. Alder and H. von Brachel, *Ann.*, **651**, 141 (1962), and intervening papers.

(2) W. G. Bickford, G. S. Fisher, L. Kyame, and C. E. Swift, *J. Am. Oil Chemists' Soc.*, **25**, 251 (1948); E. H. Farmer, *Trans. Faraday Soc.*, **38**, 340 (1942).

(3) (a) C. C. Price, "Mechanisms of Reactions at Carbon–Carbon Double Bonds," Interscience Publishers, Inc., New York, N. Y., 1946, p. 50; (b) C. S. Rondestvedt and A. H. Filbey, *J. Org. Chem.*, **19**, 548 (1954).

(4) H. P. Koch, *J. Chem. Soc.*, 1111 (1948).

(5) R. T. Arnold and J. F. Dowdall, *J. Am. Chem. Soc.*, **70**, 2590 (1948).

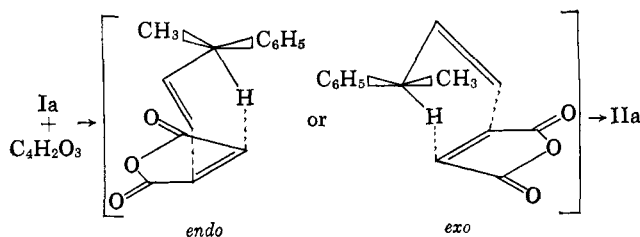(6) W. von E. Doering and W.R. Roth, *Tetrahedron*, **18**, 67 (1962).

Figure 2.

The characteristic and remarkable stereospecificity of the diene addition,[7] and indeed, of other "no-mechanism" reactions such as the Claisen and Cope rearrangements,[6,8] suggested that the transition state for the olefin–dienophile addition might also be a highly oriented one in which the relative bulk of the substituents R_1 and R_2 (in Fig. 1) would play a crucial part in determining the exact geometry.

This expectation has been realized by the finding that *use of optically active olefins of type I in the reaction with maleic anhydride leads to optically active products.*
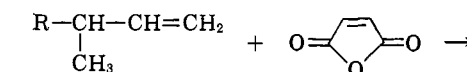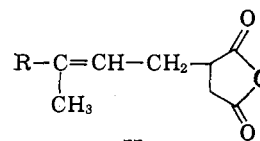
Heating a solution of $(R)(-)$-3-phenyl-1-butene (Ia),[9] $[\alpha]D$ −6.80°, and maleic anhydride in *o*-dichlorobenzene for 12 hr. at 210° led to (3-phenylbuten-2-yl) succinic anhydride (IIa), b.p. 190° (2 mm.), $[\alpha]^{20}D$ −14.5°. Optical activity was maintained while the anhydride was hydrolyzed to the acid, m.p. 101–102°, $[\alpha]^{20}D$ 5.9°, and converted, by lithium aluminum hydride reduction, to the corresponding diol (bis-*p*-toluenesulfonate, m.p. 99°, $[\alpha]^{20}D$ 2.46°). The structures assigned to these compounds are consistent with their elemental analyses and with their infrared, ultraviolet (maxima at 238–242 mμ), and n.m.r. (one olefinic proton) spectra. $(R)(-)$-3,7-Dimethyloctene-1 (Ib),[10] $[\alpha]^{20}D$ −9.30°, was heated with maleic anhydride under the same conditions for 20 hr.; distillation of the reaction mixture gave 5,9-dimethyldec-4-ene-1,2-dicarboxylic anhydride (IIb), b.p. 155° (0.2 mm.), which was also optically active, $[\alpha]^{21}D$ −1.90°.

Though it is difficult to assess the degree of retention of optical activity during these reactions,[11] several conclusions may be drawn from the results. First, the transfer of optical asymmetry from one of the reactants *to a different* site in the adduct is fully consistent with a concerted process in which all new bonds are formed essentially simultaneously.

Additional inferences may be drawn by considering the absolute configurations of products IIa and IIb. $(-)$-IIa displays a plain positive O.R.D. curve, paral-

(7) J. G. Martin and R. K. Hill, *Chem. Rev.*, **61**, 537 (1961).

(8) See S. J. Rhoads in "Molecular Rearrangements," Part 1, P. de Mayo, Ed., Interscience Publishers, New York, N. Y., 1963, p. 677 ff.

(9) D. J. Cram, *J. Am. Chem. Soc.*, **74**, 2137 (1952).

(10) Prepared from (+)-citronellal by a synthesis which will be described in our full paper.

(11) Determination of optical purity of the products is complicated by partial racemization during the reaction. In a model experiment, a 5% solution of (−)-methylsuccinic anhydride in *o*-dichlorobenzene lost 70% of its optical activity on refluxing for 24 hr.