C. **In Benzene.**—The procedure of Burger and Dawson ($MgBr_2$) was repeated with a control experiment. In the latter case the reaction became heterogeneous in about 2 hr. After 6 hr in benzene (oil bath temperature of 73°) the reactions were worked up to give 24.5 and 24 g of crude material, respectively. Gas chromatographic analysis indicated 23.4% diethyl phenylphosphonate, 21.6% ethyl diphenylphosphinate, and 55% triphenylphosphine oxide from Burger and Dawson's conditions with $MgBr_2$ and 9.8% diethyl phenylphosphonate, 11.8% ethyl diphenylphosphinate, and 78.4% triphenylphosphine oxide from the control experiment. Following digestion with diethyl ether, 30 and 58% yields of triphenylphosphine oxide were isolated from the run containing magnesium bromide and the control experiment, respectively.

Reactions of Trimethylaluminum. A. With Dodecylphosphonyl Dichloride.—To 14.5 g of trimethylaluminum (0.2 mol) under argon was added *very slowly* 28 g of dodecylphosphonyl dichloride (0.1 mol). Care was required during the addition to keep the temperature below 45° as several of these reactions blew up. After stirring overnight and heating slowly to 130° over a period of 8 hr, the mixture was cooled and solvolyzed cautiously with 50 ml of ethanol. Addition of ice-cold 1:1 hydrochloric acid gave a solution which was extracted with diethyl ether. Following removal of the ether, dissolution in chloroform, and water washing, distillation gave 17 g (71%) of dimethyldodecylphosphine oxide, mp 83–84°. Use of 0.2 mol of trimethylaluminum to 0.3 mol of dodecylphosphonyl dichloride gave a mixture of largely diethyl dodecylphosphonate and ethyl dodecylmethylphosphinate in about a 2:1 ratio.

B. **With Dialkyl Alkylphosphonates.**—Upon adding 16.5 g of trimethylaluminum to 200 ml of THF considerable heat was evolved. Addition of 30.6 g of diethyl dodecylphosphonate gave a relatively small heat effect. After refluxing 3.5 hr work-up as above gave 88% recovered diethyl dodecylphosphonate. No evidence of substitution products could be detected in the gas chromatograph or the phosphorus nmr spectrum of the crude product.

Addition of 30.6 g of diethyl dodecylphosphonate to 16.5 g of trimethylaluminum at 10° resulted in considerable heat evolution. Upon heating slowly to 70° for 3 hr, 100° for 1 hr, and reflux for 8 hr, (130–135°) ethylene and methane gas were evolved. Work-up in the manner as above gave a solid that was insoluble in water and diethyl ether. Recrystallization from acetone gave 12.3 g (43%) of aluminum tris(ethyl dodecylphosphonate).

Anal. Calcd for $C_{42}H_{90}P_3O_9Al$: C, 58.8; H, 10.6; Al, 3.1. Found: C, 59.2; H, 10.6; Al, 2.8.

Again no substitution products were detected in the crude products.

Phosphorus nmr spectra of a 3:1 mixture of diethyl ethylphosphonate–trimethylaluminum showed a signal at −32.2 ppm with a shoulder at −35.2 ppm.

In THF diethyl ethylphosphonate (−32.5 ppm) and trimethylaluminum (1:1) gave only one signal at −33.5 ppm.

Registry No.—Phenylmagnesium bromide, 100-58-3; magnesium chloride, 7786-30-3; magnesium bromide, 7789-48-2; diethyl phenylphosphonate, 1754-49-0; diethyl ethylphosphonate, 78-38-6; trimethylaluminum 75-24-1; dimethyldodecylphosphine, 871-95-4; aluminum tris(ethyl dodecylphosphonate), 17448-03-2.

Acknowledgments.—The author wishes to thank Mr. Bruce Banker for his excellent technical assistance and Dr. D. J. Peterson, Dr. C. D. Broaddus, Dr. R. G. Laughlin, and Dr. T. J. Logan for their helpful discussions.

Synthesis and Acetolysis of Mixed Trialkyl Phosphites

EARL S. HUYSER AND JERRY A. DIETER[1]

Department of Chemistry, University of Kansas, Lawrence, Kansas 66044

Received May 23, 1968

A number of mixed trialkyl phosphites were prepared by reaction of the appropriate mono- or dialkyl chlorophosphite and alcohol in an inert solvent in the presence of N,N-dimethylaniline. Reaction of these mixed trialkyl phosphites with acetic acid at 125° resulted in formation of a mixture of acetate esters and dialkyl phosphites. Analysis of the acetate esters produced in this manner served as a means of determining the nature of the acetolysis of various alkyl groups from trialkyl phosphites.

The dealkylation reactions of phosphite esters with hydrogen halides yielding an alkyl halide and a phosphite ester with one less alkyl group have been extensively studied by Gerrard and his coworkers.[2] They found that (1) the reactions of trialkyl phosphites with a hydrogen halide were faster than those of dialkyl phosphites and monoalkyl phosphites; (2) the removal of the alkyl group occurred with inversion of configuration in the trialkyl and dialkyl phosphites, whereas extensive racemization was observed in the reactions of monoalkyl phosphites having an optically active alkyl group; and (3) the order of reactivity of the hydrogen halides with a given trialkyl halide was HI > HBr > HCl. Reactions of trialkyl phosphites with sulfuric acid yielding sulfate esters have been reported.[3] Similarly, reactions of trialkyl phosphites with mono- and dialkyl phosphates yielding the trialkyl phosphates are known.[4] Carboxylic acids have been reported to react at elevated temperatures (110–170°) with equivalent amounts of triethyl phosphite yielding the ethyl carboxylate and diethyl phosphite.[5] Esterification of furylacrylic acid was accomplished by heating the acid for 3 hr at 150–160° with triethyl phosphite.[6] Reactions of dialkyl phosphites with carboxylic acids are also known but occur more slowly at the conditions used for the reactions with trialkyl phosphites.[7]

The work described in this article is concerned with the acetolysis reactions of several mixed trialkyl phosphites. The purpose of this study was to determine

(1) Taken from the Ph.D. thesis submitted by J. A. D. to the University of Kansas, 1966.

(2) W. Gerrard, *J. Chem. Soc.*, 1464 (1940); W. Gerrard, *ibid.*, 85 (1944); W. Gerrard, *ibid.*, 848 (1945); M. C. Berla and W. Gerrard, *ibid.*, 2309 (1949); W. Gerrard and E. G. G. Whitbread, *ibid.*, 914 (1952); V. F. G. Cooke and W. Gerrard, *ibid.*, 1978 (1955); T. M. Cook, E. J. Coulson, W. Gerrard, and H. R. Hudson, *Chem. Ind.* (London), 1506 (1962); E. J. Coulson, W. Gerrard, and H. R. Hudson, *J. Chem. Soc.*, 2364 (1965).

(3) A. E. Arbuzov and P. I. Alimov, *Izv. Akad. Nauk SSSR, Otd. Khim. Nauk*, 268 (1951).

(4) C. Walling, F. W. Stacey, S. E. Jamison, and E. S. Huyser, *J. Amer. Chem. Soc.*, **80**, 4546 (1958).

(5) G. Kamami', V. A. Kukhtin, and O. A. Strogova, *Tr. Kazansk. Khim. Teknol. Inst.*, **21**, 155 (1956).

(6) A. E. Arbuzov and V. M. Zoroastrova, *Izv. Akad. Nauk SSSR, Otd. Khim. Nauk*, 1030 (1960).

(7) F. W. Hoffmann and H. D. Wiess, *J. Amer. Chem. Soc.*, **79**, 4759 (1957).

TABLE I

SYNTHESIS OF MIXED TRIALKYL PHOSPHITES

$(RO)_2PCl + R'OH \longrightarrow (RO)_2POR' + HCl$

$(RO)_2PCl$	R'OH	Product	Bp, °C (mm)	% yield	Calcd, % C	Calcd, % H	Calcd, % P	Found, % C	Found, % H	Found, % P
Ethyl	2-Octanol	Diethyl-2-octyl phosphite (III)	74–80 (0.5–1.0)	31	57.57	10.87	12.38	57.55	10.83	12.45
Ethyl	*d*-(+)-2-Octanol[a]	Diethyl-(+)-*d*-2-octyl phosphite (IV)[b]	74–80 (0.5–1.0)	30	...	...	...	...	...	...
Ethyl	*trans*-Crotyl alcohol	Diethyl-*trans*-crotyl phosphite (V)	60–61 (12)	21	49.99	8.92	16.12	49.66	8.79	16.42
Ethyl	α-Methyallyl alcohol	Diethyl-α-methallyl phosphite (VI)	44–46 (0.5–1.0)	10	49.99	8.92	16.12	50.09	8.82	16.10
Ethyl	*exo*-Norbornyl alcohol	Diethyl-*exo*-norbornyl phosphite (VII)	64 (0.3)	15	56.88	9.11	13.34	56.87	9.18	13.03
Ethyl	*endo*-Norbornyl alcohol	Diethyl-*endo*-norbornyl phosphite (VIII)	62–64 (0.3)	17	56.88	9.11	13.34	57.16	9.16	13.82

$ROPCl_2 + 2R'OH \longrightarrow (R'O)_2POR + 2HCl$

$ROPCl_2$										
Ethyl	Isopropyl alcohol	Ethyldiisopropyl phosphite (II)[c]	75–77 (25)	18	...	...	...	...	...	...
Isopropyl	Ethyl alcohol	Diethylisopropyl phosphite (I)	61–63 (20)	43	46.66	9.51	17.19	46.74	9.35	16.74
Cyclohexyl	Ethyl alcohol	Diethylcyclohexyl phosphite (IX)	122–125 (20)	17	54.53	9.61	14.07	54.87	9.71	14.24

[a] $[\alpha]^{27}D$ +9.2 (*c* 10.0, ethanol). [b] $[\alpha]^{26}D$ +4.8 (*c* 10.2, ethanol). [c] Lit. bp 65–65.5 (18 mm). G. Kamai' and R. M. Kharrasova *Zh. Obshch. Khim.*, **27**, 953 (1957).

both the relative ease of removal of various alkyl groups and the structure of the acetate esters in cases where isomers could be formed in order to deduce mechanisms for these dealkylation reactions.

Results

With the exception of ethyldiisopropyl phosphite and diethylcyclohexyl phosphite, the mixed trialkyl phosphites used in this study were synthesized by reaction of diethyl chlorophosphite and the appropriate alcohol in either diethyl ether or pentane in the presence of N,N-dimethylaniline. The mixed phosphites prepared in

$$\begin{matrix} RO \\ \diagdown \\ \quad PCl \\ \diagup \\ RO \end{matrix} + R'OH + C_6H_5N(CH_3)_2 \longrightarrow \begin{matrix} RO \\ \diagdown \\ \quad POR' \\ \diagup \\ RO \end{matrix} + C_6H_5NH(CH_3)_2^+ Cl^- \quad (1)$$

this manner and used in the acetolysis studies are listed in Table I. Ethyldiisopropyl phosphite was prepared by reaction of ethyl dichlorophosphite with isopropyl alcohol in the same manner employed for the other phosphites. Diethylcyclohexyl phosphite was prepared by reaction of cyclohexyl dichlorophosphite with ethanol in the pentane in the presence of N,N-dimethylaniline.

The acetolysis reactions were accomplished by heating a mixture of about equivalent amounts of the mixed trialkyl phosphite and acetic acid sealed in a Pyrex tube at 125° for about 12 hr. During this period, an appreciable amount of the trialkyl phosphite reacted, but little, if any, of the dialkyl phosphite produced in the reaction underwent acetolysis. We found that when reaction of the dialkyl phosphite was allowed to occur by using more than an equivalent of acetic acid and a longer period of heating, a heterogeneous mixture resulted owing to the insolubility of the monoalkyl phosphite in the nonpolar mixture of acetate esters and dialkyl phosphites. The results shown in Tables II–V were obtained from reactions in which no evidence of acetolysis of the dialkyl phosphite was observed. The relative reactivity ratios $k_{ROAc}/k_{R'OAc}$ were determined from the amounts of the acetate esters as determined by gas chromatographic analysis of

TABLE II

ACETOLYSIS OF MIXED TRIALKYL PHOSPHITES

Phosphite	Phosphite, mmol	HOAc, mmol	Ethyl acetate	Alkyl acetate	k_{ROAC}/k_{EtOAc}[a]
Ethyldiisopropyl phosphite (II)	5.14	5.22	0.74	2.13	1.43
	5.48	6.02	0.87	2.52	1.45
	5.34	4.74	0.75	2.15	1.43
Diethylisopropyl phosphite (I)	5.66	5.72	2.07	1.14	1.10
	5.63	5.86	2.37	1.21	1.02
Diethyl-2-octyl phosphite (III)	4.03	4.51	0.81	1.04	2.5
	4.10	4.53	0.74	10.3	2.8

[a] Corrected for statistical factor.

TABLE III

ACETOLYSIS REACTIONS OF DIETHYL-*trans*-CROTYL PHOSPHITE (V) AND DIETHYL-α-METHALLYL PHOSPHITE (VI)

Phosphite	Phosphite, mmol	HOAc, mmol	Ethyl acetate	Crotyl acetate	α-Methallyl acetate	k_{ROAc}/k_{EtOAc}[a]
Diethyl-*trans*-crotyl phosphite	5.60	5.88	1.13	2.33	0.96	5.9
	5.24	5.26	1.72	2.02	1.26	3.8
Diethyl-α-methallyl phosphite	5.36	5.16	0.42	0.90	1.89	13.3
	5.26	5.20	0.48	0.87	1.97	11.8
	5.22	5.36	0.43	0.88	2.20	14.7

[a] Determined from the combined crotyl and α-methallyl acetates and statistically corrected.

TABLE IV

REACTIONS OF DIETHYL *exo*- AND *endo*-NORBORNYL PHOSPHITES WITH ACETIC ACID

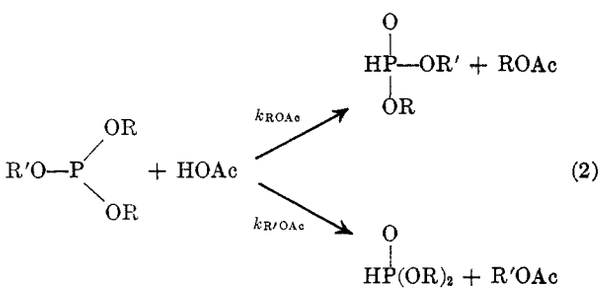
Phosphite	Phosphite, mmol	Acetic acid, mmol	Ethyl acetate, mmol	Norbornyl acetate, mmol	*exo*-Norbornyl acetate, %	k_{ROAc}/k_{EtOAc}
Diethyl-*exo*-norbornyl phosphite (VII)	4.46	4.55	3.01	1.25	100	0.83
	4.31	4.41	3.63	1.50	100	0.83
Diethyl-*endo*-norbornyl phosphite (VIII)	4.31	4.42	1.79	0.64	75	0.71
	4.33	4.37	2.04	0.79	82	0.77

TABLE V

ACETOLYSIS OF DIETHYLCYCLOHEXYL PHOSPHITE (IX)

Phosphite, mmol	HOAc, mmol	Ethyl acetate	Cyclohexyl acetate	Cyclohexene
4.56	4.50	1.78	0.37	1.10
4.77	4.72	2.13	0.43	1.49
4.71	4.98	2.74	0.47	1.50
4.67	0.48	0.16		0.72
4.50	0.58	0.23		0.64

the reaction mixtures. In all cases, two or more runs were made for each mixed phosphite.



(2)

The acetolysis reactions of diethylisopropyl phosphite and ethyldiisopropyl phosphite showed that the secondary alkyl group was removed somewhat more readily than the primary group and that the ease of removal was dependent on the particular phosphite used (Table II). In the case of diethyl-*dl*-2-octyl phosphite, the secondary alkyl group is relatively more reactive toward acetolysis than the isopropyl group. Acetolysis of diethyl-(+)-2-octyl phosphite (IV) (93% optical purity) yielded (−)-2-octyl acetate with an optical purity of 84–89% indicating a total inversion of 92–94% in the reaction. The results of these experiments indicate that secondary alkyl groups are removed more readily than primary ethyl groups and that acetolysis reactions occur with over 90% inversion of configuration.

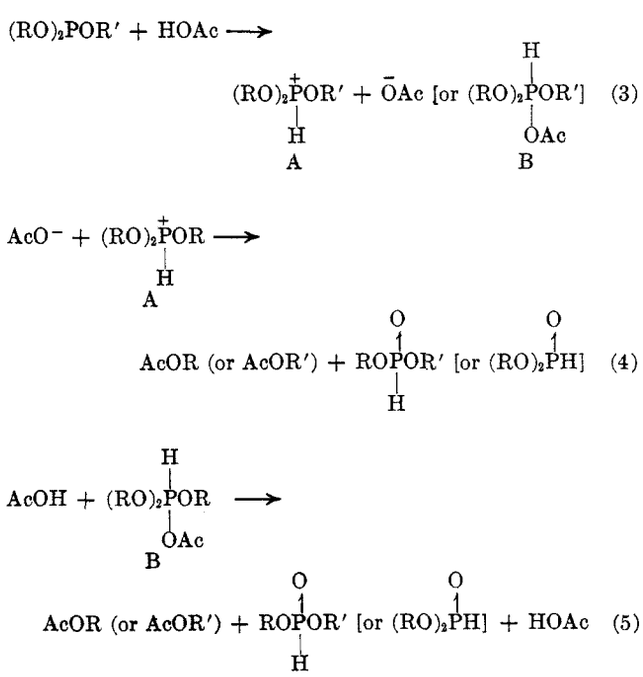
The crotyl group was removed about five times faster than the ethyl group in the acetolysis of diethyl-*trans*-crotyl phosphite. Furthermore, the acetolysis of the crotyl group gave a mixture of crotyl and α-methallyl acetates in which the former predominated (Table III). Diethyl-α-methallyl phosphite reacted with acetic acid yielding a mixture of acetate esters in which α-methallyl acetate predominated over the crotyl acetate. In this case, the acetolysis of the α-methallyl group, a secondary group, was about 13 times more facile than that of the ethyl group.

Diethyl-*exo*-norbornyl phosphite reacted in a somewhat anomalous manner in that the norbornyl group underwent acetolysis with complete retention of configuration (Table IV). The norbornyl acetate formed from the acetolysis of the diethyl-*endo*-norbornyl phosphite is mainly that resulting from inversion of configuration at the reaction site although some retention was observed. It is also interesting to note that the norbornyl group is less reactive than the ethyl group in both cases toward acetolysis.

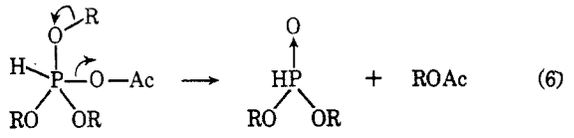
The course of the acetolysis of diethylcyclohexyl phosphite was unusual in that cyclohexene was a major reaction product (Table V). The alkene did not result from pyrolysis of cyclohexyl acetate since heating a mixture of this ester with diethyl phosphite did not yield any detectable amounts of cyclohexene. Interestingly, reaction of diethylcyclohexyl phosphite with about 10 mol % acetic acid resulted in formation of a greater than stoichiometric amount of cyclohexene along with ethyl acetate. These observations suggest that acetic acid may play what amounts to a catalytic role in forming cyclohexene from this mixed trialkyl phosphite and that the reaction path for acetolysis of this phosphite ester is different from those of the others in which no detectable amounts of alkene were observed.

Discussion

A plausible mechanism for the acetolysis of mixed trialkyl phosphites having only primary and secondary alkyl groups is one in which either the phosphonium ion (A) or the pentacovalent adduct (B) undergoes nucleophilic attack by acetate ion or acetic acid, respectively, producing the acetate ester and a dialkyl phosphite. The 92–94% inversion of configuration observed in the acetolysis of the (+)-2-octyl group of diethyl-(+)-2-octyl phosphite (IV) indicates that an SN2 displacement on the alkyl group is the predominant course of reaction in these simpler systems. The fact that complete inversion is not observed suggests that some fragmentation of the phosphonium ion (A) (SN1



reaction) competes with the SN2 displacement. It is also possible, however, that an SNi reaction of the pentacovalent species yielding an acetate with retention of configuration may occur.[8] Evidence supporting



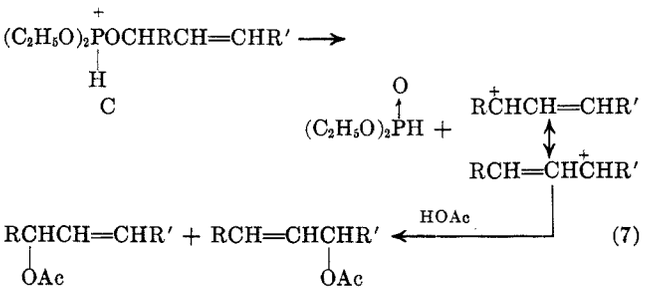
(6)

the SNi reaction is found in the reactions of the diethylnorbornyl phosphites (VII and VIII) and will be discussed subsequently in this article.

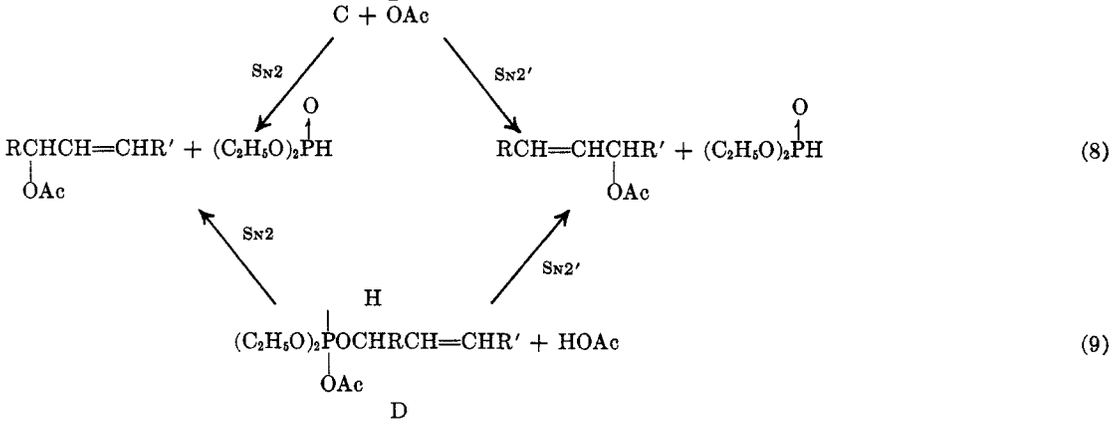
One explanation for the higher reactivity of secondary alkyl groups with respect to primary may be the greater role relief of steric factors in the leaving groups play relative to steric effects in the region of the carbon atom undergoing nucleophilic attack. Nucleophilic attack at the isopropyl group (of either A or B) will result in displacement of diethyl phosphite, a relatively strain-free species. On the other hand, attack on an ethyl group, although preferable from the standpoint of the steric requirements for the alkyl group undergoing attack, results in displacement of ethylisopropyl phosphite. Both the displaced dialkyl phosphite and the species undergoing attack contain phosphorus with a tetrahedryl configuration and consequently subjected to steric problems caused by secondary alkyl groups. Nucleophilic attack at the secondary alkyl group would result in relief of steric strain in the phosphorus moiety whereas attack at the ethyl group would have no effect in relieving steric strain.

The observation that an isopropyl group is relatively more reactive than an ethyl group in ethyldiisopropyl phosphite (II) than in diethylisopropyl phosphite (I) (see Table II) can also be explained in terms of similar steric factors. The relief of strain resulting from removal of one of the two isopropyl groups from the reaction intermediate derived from II yielding ethyl isopropyl phosphite is likely more pronounced than that resulting from removal of the single isopropyl group in the reaction of I. It should also be noted that the 2-octyl group in III, probably because of its size and the larger number of possible conformations it can assume, introduces more strain than the smaller isopropyl group and is more reactive toward acetolysis relative to ethyl than is the isopropyl group in I or II.

The acetolysis reactions of the allylic groups of diethyl-*trans*-crotyl phosphite (V) and the diethyl-α-methylallyl phosphite (VI) also showed SN2 character. Both phosphites gave a mixture of crotyl acetate and α-methylallyl acetate, but the acetate with the allylic structure present in the parent phosphite predominated in each case (Table III). Although the formation of the isomeric allylic acetate may have resulted from some ionization of the phosphonium cation yielding the allylic carbonium ion (SN1 path shown in reaction 7), other routes to the isomeric acetates are also available. One is an SN2′ attack of either the phosphonium



(7)



(8)

(9)

R = H; R′ = CH_3 for V; and R = CH_3 and R′ = H for VI

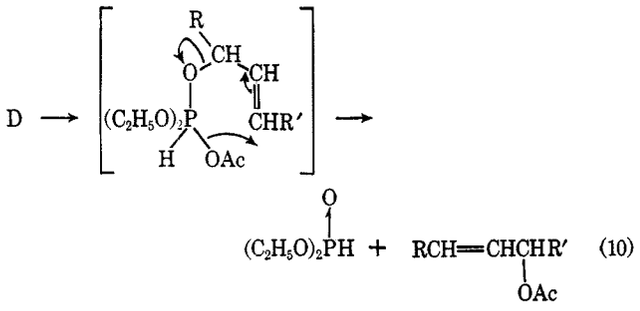
ion (C, eq 8) or the pentacovalent adduct (D, eq 9) at the unsaturated linkage[9] competing with the SN2 reaction. If this were the case, more crotyl acetate, the rearranged product, would have been expected from the reaction of VI with the less hindered γ carbon and hindered α carbon than α-methallyl acetate, the rearranged product, from V. The amounts of the isomeric acetate were about the same. Another possible explanation is that the isomeric acetates resulted from an SNi′ reaction[10] of the pentacovalent adduct as shown in reaction 10.

The allylic groups in both V and VI are more reactive toward SN2 displacement than the ethyl group. It is interesting that the reactivity of the secondary α-methylallyl group in VI is markedly more reactive than the primary crotyl group in V. This observation is consistent with the preferential displacement on a

(8) Reactions of pentavalent phosphorus species yielding products with retention of configuration have been reported by Huckel and Pietrzak who found menthyl chloride produced in the reaction of menthol with PCl_5: W. Huckel and H. Pietrzak, *Ann.*, **540**, 250 (1939).

(9) R. H. de Wolfe and W. G. Young, *Chem. Rev.*, **56**, 769 (1956).

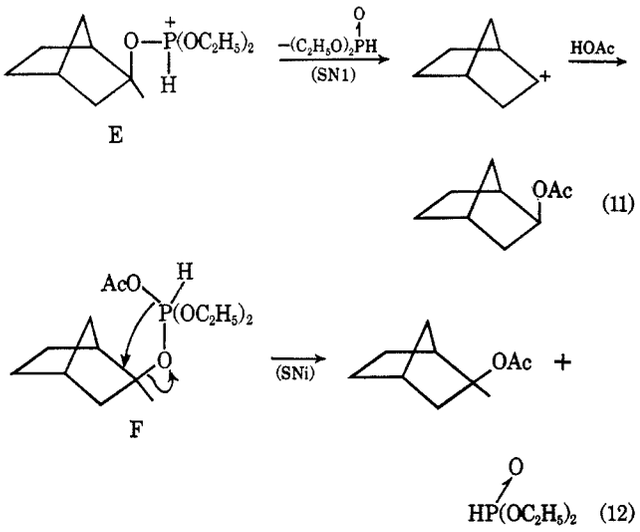
(10) J. D. Roberts, W. G. Young, and S. Winstein, *J. Amer. Chem. Soc.*, **64**, 2127 (1942); W. G. Young, F. F. Caserio, and D. Brandon, *Science*, **117**, 473 (1953); F. F. Caserio, G. E. Dennis, R. H. DeWolfe, and W. G. Young, *J. Amer. Chem. Soc.*, **77**, 4182 (1955).



(10)

secondary alkyl group because of relief of strain in the displaced dialkyl phosphite.

The formation of only *exo*-norbornyl acetate in the acetolysis reactions of diethyl-*exo*-norbornyl phosphite (VII) suggests that the norbornyl cation, which could result from the fragmentation of the protonated species E (reaction 11), is an intermediate in the reaction. Although the norbornyl cation would yield exclusively the *exo*-norbornyl acetate,[11] this acetate could result from an SNi reaction of the pentacovalent species F (reaction 12). Steric hindrance is very likely responsible for the lack of any *endo*-norbornyl acetate resulting from an SN2 attack of the norbornyl moiety of either E or F.

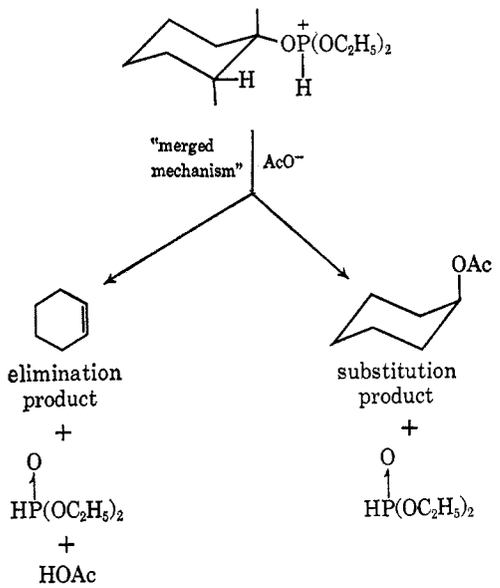


(11)

(12)

The formation of both the *endo*- and *exo*-norbornyl acetates in the reactions of VIII (see Table IV) supports the suggestion that SNi reactions may occur in these systems. In this case, steric hindrance toward SN2 attack at the norbornyl moiety from the *exo* side is not as great, and the SN2 reaction yielding *exo*-norbornyl acetate can compete with the SNi reaction yielding the isomeric *endo*-norbornyl acetate. Indeed, it becomes difficult to conceive of a mechanism in this case other than the SNi mechanism to account for the formation of *endo*-norbornyl acetate.

The formation of cyclohexene as the major product of the acetolysis of the cyclohexyl moiety of diethylcyclohexyl phosphite (IX) requires some explanation. Cyclohexyl acetate, the expected product resulting from acetolysis of the cyclohexyl moiety, was not a precursor of the alkene since it proved to be relatively stable under the conditions of our experiments. The alkene may have resulted from the nucleophilic attack on the cyclohexyl moiety in a "merged mechanism."[12] The expected preferred conformers for either the cation or the pentacovalent species would be those in which the leaving group (the diethyl phosphite moiety) would most likely be in an equatorial position. The preferential formation of the alkene by attack of a β hydrogen by a relatively weak nucleophile (AcO^- or AcOH) rather than the SN2 product is similar to reactions of other cyclohexane derivatives with weakly nucleophilic reagents. It is interesting to note also that the amount of fragmentation of IX into diethyl phosphite and cyclohexene is larger than the amount of acetic acid originally present. This "catalytic effect" of acetic



acid on the fragmentation of IX into cyclohexene and diethyl phosphite is consistent with the "merged mechanism" concept for the reaction of this mixed phosphite.

Experimental Section

Preparation of Mixed Trialkyl Phosphites (Table I).—Diethyl chlorophosphite was prepared by refluxing a 2:1 molar mixture of triethylphosphite and phosphorus trichloride for approximately 1 hr, during which time the liquid assumed a yellow color. Distillation of the mixture gave diethyl chlorophosphite (bp 32–42° at 25 mm) in about 80% yield. Diethylcrotyl phosphite (V), diethyl-α-methylallyl phosphite (VI), diethyl-2-octyl phosphite (III), diethyl-*exo*-norbornyl phosphite (VII), diethyl-*endo*-norbornyl phosphite (VIII), and diethyl-(±)-2-octyl phosphite (IV) were prepared from diethyl chlorophosphite as follows. About 10 g of the alcohol and an equivalent amount of N,N-dimethylaniline in 125 ml of dry Skelly F was added slowly to a mixture of diethyl chlorophosphite in an amount equivalent to the alcohol which was dissolved in 250 ml of Skelly F. The reaction mixture was vigorously stirred with cooling in an ice bath during the addition. The amine hydrochloride was filtered from the reaction mixture, and the Skelly F was removed under reduced pressure. The remaining residues were subjected to vacuum distillation and yielded the mixed phosphites in the amounts shown in Table I.

Diethylisopropyl phosphite (I) and diethylcyclohexyl phosphite (IX) were prepared in the following manner. Phosphorus trichloride (68.8 g, 0.5 mol) was dissolved in 700 ml of dry diethyl ether and an equimolar amount of either isopropyl alcohol or cyclohexanol and N,N-dimethylaniline was added slowly to the phosphorus trichloride–ether mixture with vigorous stirring and cooling of the flask by means of an ice bath. When addition of the alcohol was completed, ethanol (45 g, 1.0 mol) and N,N-dimethylaniline (121 g, 1.0 mol) were added with stirring to the

(11) S. Winstein and D. Trifan, *J. Amer. Chem. Soc.*, **74**, 1154 (1952).

(12) S. Winstein, D. Darwish, and H. J. Holness, *ibid.*, **78**, 2915 (1956); E. Eliel and R. G. Haber, *ibid.*, **81**, 1249 (1959).

mixture. The amine hydrochloride was filtered from the reaction mixture; the ether was removed under vacuum; and the remaining residue was distilled. The mixed phosphites were formed in the amounts shown in Table I.

Ethyl dichlorophosphite (50 g, 0.34 mol), prepared by reaction of equimolar amounts of phosphorus trichloride and ethanol in dry diethyl ether,[13] was added to a mixture of N,N-dimethylaniline (82.4 g, 0.67 mol) and isopropyl alcohol (40.8 g, 0.68 mol) dissolved in 500 ml of dry Skelly F. During the addition of the ethyl dichlorophosphite, the reaction flask was cooled in an ice bath, and the mixture was stirred vigorously. After removal of the amine hydrochloride by filtration and the Skelly F by distillation at atmospheric pressure, the remaining residue was distilled under vacuum yielding ethyldiisopropyl phosphite (see Table I).

In all cases, the ir and nmr spectra of the mixed phosphite esters were consistent with their assigned structures.

Reactions of Mixed Phosphites with Acetic Acid.—The quantities of acetic acid and mixed phosphites shown in Tables II–V were sealed in Pyrex tubes and heated for approximately 12 hr in a constant temperature oil bath set at 125°. During this period of heating, the mixtures remained homogeneous. Upon cooling, the tubes were opened, and an accurately weighed amount of the reaction mixture was added to a known amount of an inert compound (chlorobenzene, toluene, tetralin or anisole) which served as an internal standard for the gas chromatographic analysis. The amounts of the ethyl acetate and other alkyl acetate produced in the reaction were determined from comparison of their gas chromatographic peak areas with that of the internal standard. Duplicate or triplicate runs were made for each mixed phosphite.

Separation of *exo*- and *endo*-norbornyl acetates could not be accomplished by gas chromatographic analysis. The compositions of these norbornyl acetates produced in these reactions (Table IV) were determined by ir analysis of the norbornyl acetates which were separated from the reaction mixtures by preparative gas chromatography using a 10 ft × $^3/_8$ in. column packed with 30% phenyldiethanolamine on Chromosorb W. Acetolysis of 0.99 g (4.3 mmol) of diethyl-*exo*-norbornyl phosphite with 0.26 g (4.4 mmol) of acetic acid at 125° for 12 hr yielded on isolation 50.9 mg of *exo*-norbornyl acetate with an ir spectrum identical with that of an authentic sample. Acetolysis of diethyl-*endo*-norbornyl phosphite (1.00 g, 4.3 mmol) with acetic acid (0.26 g, 4.4 mmol) at 125° for 12 hr yielded on isolation 25.9 mg of norbornyl acetates. Ir analysis showed the characteristic absorption at 1072 cm^{-1} displayed by *exo*-norbornyl acetate as well as an absorption at 1039 cm^{-1} found in the spectrum of an authentic sample of *endo*-norbornyl acetate. The amounts of the *endo*- and *exo*-norbornyl acetates were determined from the relative intensities of the absorptions by comparing them with the intensities observed for synthetic mixtures of the two esters.

Acetolysis of Diethyl-(+)-2-octyl Phosphite.—Diethyl-(+)-2-octyl phosphite (2.01 g, 8.03 mmol) and acetic acid (0.481 g, 8.01 mmol) were heated for 12 hr at 125°. The 2-octyl acetate formed was separated from the reaction mixture by preparative gas chromatography on a 20 ft × $^3/_8$ in. column packed with 30% Carbowax on Chromosorb P. The isolated 2-octyl acetate, which amounted to 0.142 g, had a specific rotation of $[\alpha]^{27}D$ −2.6 (*c* 11.2, ethanol). In a similar reaction employing 1.15 g (4.62 mmol) of diethyl-(+)-2-octyl phosphite and 0.28 g (4.7 mmol) of acetic acid, 0.125 g of 2-octyl acetate was isolated which had $[\alpha]^{27}D$ −2.7 (*c* 10.0, ethanol).

Registry No.—I, 17448-38-3; II, 14540-27-3; III, 17448-39-4; IV, 17448-40-7; V, 17448-41-8; VI, 17448-42-9; VII, 17448-43-0; VIII, 17448-44-1; IX, 17448-45-2.

(13) R. W. Young, K. H. Wood, R. J. Joyce, and G. W. Anderson, *J. Amer. Chem. Soc.*, **78**, 2126 (1956).

The Synthesis of Methyl 13,16-Cycloatisan-18-oate (Methyl *anti*-Trachylobanate)[1,2]

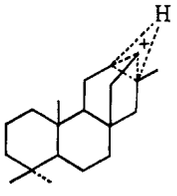
WERNER HERZ, R. N. MIRRINGTON, HARRY YOUNG, AND YONG YENG LIN

Department of Chemistry, The Florida State University, Tallahassee, Florida 32306

Received May 20, 1968

The synthesis of the pentacyclic diterpene methyl 13,16-cycloatisan-18-oate, the enantiomer of methyl trachylobanate, is described. The successful route involved as the initial step the condensation of methyl levopimarate with *n*-butyl crotonate. The major adduct whose structure and stereochemistry were elucidated was transformed by oxidation with potassium permanganate, ozonolysis, reduction with chromous chloride, and oxidative decarboxylation to 8-carboxymethyl-2,5a,8-trimethyl-1H-3,10a-Δ^1-decahydroethanophenanthren-12-one (**30a**). Cationically induced cyclization of the major alcohol obtained by hydride reduction of **30** gave the title compound. Other approaches to the trachylobane system are presented.

The trachylobanes or *ent*-13,16-cycloatisanes[3-5] (**1**) comprise a class of interesting pentacyclic diterpenes which were isolated[4] from the seed pods of *Trachylobium verrucosum* Oliv. Their importance stems from the circumstance that their occurrence in nature completes the array of diterpenoids theoretically derivable from the ion A which has been suggested[6] as the common intermediate leading to tetracyclic diterpenes and in fact helps to substantiate current notions concerning the biogenesis of diterpenes in general.



A

Our interest in the transformation of common resin acids into diterpenes with novel skeletons[7,8] prompted us to examine possible routes to the partial synthesis of this interesting pentacyclic skeleton. We have

(1) Resin Acids. XIV. A preliminary communication has appeared. W. Herz, R. N. Mirrington, and H. Young, *Tetrahedron Lett.*, 405 (1968).

(2) Supported in part by grants from the Petroleum Research Fund of the American Chemical Society and the National Science Foundation (GP-6362).

(3) In deference to the discoverers[4] of this series of compounds, we shall refer to **1a** as trachylobane and **1b** as trachylobanic acid. However, in accordance with a proposal for systematic nomenclature subscribed to by most workers in this area,[5] the preferred systematic name for **1a** is enantiomeric 13,16-cycloatisane (**2a**) or *ent*-13,16-cycloatisane; **1b** would then be *ent*-13,16-cycloatisan-18-oic acid. The preferred[6] common names for **2a** and **2b** are *anti*-trachylobane and *anti*-trachylobanic acid.

(4) G. Hugel, L. Lods, J. M. Mellor, D. W. Theobald, and G. Ourisson, *Bull. Soc. Chim. Fr.*, 1974 (1963); 2282, 2888 (1965). G. Hugel, L. Lods, J. M. Mellor, and G. Ourisson, *ibid.*, 2894 (1965).

(5) J. W. Rowe, in preparation.

(6) E. Wenkert, *Chem. Ind.* (London), 282 (1955).

(7) W. Herz and R. N. Mirrington, *J. Org. Chem.*, **30**, 3195 (1965).

(8) W. Herz, A. R. Pinder, and R. N. Mirrington, *ibid.*, **31**, 2257 (1966).