90 min. Working up in the usual way gave an oil (136 mg) which slowly crystallized. This, after being crystallized three times from ethyl acetate–hexane, then once from benzene–hexane, gave fat needles (53 mg, 32%): mp 122–122.5°; $\lambda_{max}^{95\%\ EtOH}$ 212 mμ (ϵ 12,000); ν_{max} (KCl disk) 3.35, 5.9, 6.13, and 12.0 μ. Its nmr spectrum (acetone-d_6) showed broad singlets at δ 1.32 (6 H), 1.96 (3 H), 2.52 (2 H), 6.97 (H), and 9.7 (2 H).

Anal. Calcd for $C_7H_{12}\ (CO_2H)_2$: C, 58.05; H, 7.58; neut equiv, 93. Found: C, 58.12; H, 7.39; neut equiv, 96.

Isomerization of 5a. A. By Heat.—The photoproduct (1.26 g, 97%, containing two main impurities) was sealed in a thick-walled glass tube and kept at 330° for 1 hr. Distillation of the product yielded an oil (739 mg, 59%) which was found, by glpc, to contain mainly one new isomer (**16**, 54%), an unidentified component (10%), and two compounds identified as 1,2,4-trimethylbenzene (8%) and 1,2,3-trimethylbenzene (8%). The latter two, isolated by glpc (squalane column), gave nmr spectra in agreement with these assignments, and gave the reported infrared spectra.[42] The main pyrolysis product, which was partly separated by glpc, using the capillary column, into two components (*ca.* 9:1), had λ 190 mμ (ϵ 14,000), 211 mμ (ϵ 2000); it also showed λ_{max} 258 mμ (ϵ 850) which can be attributed to the minor component. It gave infrared maxima at 3.24, 3.28, 3.39 (s), 3.42, 3.48, 5.6, 5.87 (s), 6.09 (s), 6.20, 6.09 (s), 7.3, 7.51, 7.78, 8.15, 8.7 (w), 8.91 (w), 9.21, 9.4, 9.59, 9.7, 9.86, 10.13, 10.33, 10.83, 11.3 (s), 11.7, 12.1, 12.7, 13.3, 13.8–14.0, and 14.9 μ (s). Its nmr spectrum ($CDCl_3$) showed one three-proton doublet (J = 7.2 cps) at δ 0.87 and another (J = 7.1 cps) at 0.96, singlets with fine splitting at 1.65 (3 H) and 4.73 (2 H), a two-proton complex at 5.64, and additional one-proton resonances located by double irradiation at 2.1 and 2.8. A singlet at δ 0.95 (0.7 H) is attributed to the contaminant. A one-proton resonance at δ 2.0–2.8 was not localized.

Anal. Calcd for $C_{10}H_{16}$: C, 88.16; H, 11.84. Found: C, 88.15; H, 11.60.

When refluxed for 4 hr under nitrogen with 5% platinized charcoal, the photoproduct was partly (50%) isomerized to the same cyclopentene (**16**); this was the only major product and was identified by its infrared spectrum after being isolated by glpc.

The cyclopentene (**16**, 83 mg) was hydrogenated in pentane in the usual way. It absorbed 2.3 equiv of hydrogen and gave two main products (73 and 15%). After purification by glpc the major product (98% pure) gave infrared and nmr spectra virtually identical with those obtained by Sisido[33] for **17a**.

Anal. Calcd for $C_{10}H_{20}$: C, 85.63; H, 14.37. Found: C, 85.74; H, 14.16.

The second tetrahydro product was found by glpc and infrared spectrum, to be **17b**. It probably resulted from the impurity present in the pyrolysis product.

B. With Acid.—The photoproduct (3.9 g, *ca.* 94%) was intimately mixed with dry, acid-washed alumina (Woelm, grade I, 43 g) which rapidly became warm. The next day the product was extracted with ether in a Soxhlet extractor and fractionated through an 18-in. spinning-band column. This yielded a small amount of starting material, but the main product was the isopropenylcyclopentene (**18**) (45% yield). The best fraction (95% by capillary column analysis) had bp 86–87° (82 mm). Spectral properties are as follows: λ_{max} 227 mμ (ϵ 435) impurity, 210 (2000), 190 (14,000); ν_{max} 3.25, 3.29, 3.38–3.5 (s), 5.62 (w), 6.10 (s), 6.89 (s), 7.26, 7.55, 7.78, 8.6 (w), 9.3, 9.82, 10.2 (w), 10.4 (w), 10.75, 11.25 (s), and 12.5 μ. Its nmr spectrum showed a three-proton doublet (J = 6.5 cps) at δ 1.05 and finely split singlets at 1.74 (6 H) 2.4 (1 H), 4.86 (2 H), and 5.43 (H), and uncharacterized multiplets (2 H) in the 2.1–2.8 region.

Anal. Calcd for $C_{10}H_{16}$: C, 88.16; H, 11.84. Found: C, 88.21; H, 11.68.

The cyclopentene (**18**, 112 mg) was added to a prereduced suspension of 5% platinized charcoal (200 mg) in pentane (10 ml) and stirred overnight under hydrogen, of which 2.03 equiv were absorbed. The main tetrahydro product (78%), separated by glpc, gave an infrared spectrum virtually identical with that[33b] of **17b**.

Anal. Calcd for $C_{10}H_{20}$: C, 85.63; H, 14.37. Found: C, 85.68; H, 14.26.

The second component (15%), on isolation by glpc, gave the infrared spectrum of **17a**.

Registry No.—**1a**, 17202-17-4; **1b**, 17202-18-5; **1c**, 17202-19-6; **1d**, 17202-20-9; **3**, 17202-21-0; **5a**, 3742-45-8; **7**, 3742-46-9; **8**, 17202-24-3; **9**, 3742-47-0; **11**, 4779-85-5; **12**, 17202-15-2; **13**, 17202-16-3; **16**, 3739-75-1; **17a**, 17202-27-6; **17b**, 17202-28-7; **18**, 3739-77-3.

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[42] "Documentation of Molecular Spectroscopy," Verlag Chemie, Weinheim, 1958, infrared spectra cards no. 212 and 215.

The Reactions of Triphenylphosphine with α-Haloisobutyrophenones and with α-Mesyloxyisobutyrophenone[1]

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α-Bromoisobutyrophenone **7** reacts with triphenylphosphine in aprotic solvents *via* elimination of hydrogen bromide to give methacrylophenone **11** and the β-ketophosphonium bromide which results from the addition of hydrogen bromide and triphenylphosphine to **11**. Debromination of **7** to isobutyrophenone occurs with triphenylphosphine in the presence of methanol. α-Chloro- and α-mesyloxyisobutyrophenone give the corresponding β-ketophosphonium salt upon reaction with triphenylphosphine. The reaction of isopropylidenetriphenylphosphorane with benzoyl chloride gives an α-ketophosphonium bromide which can be distinguished from the above-mentioned β-ketophosphonium bromide *via* its nmr spectrum. The relationships of these elimination reactions to other reactions of α-bromo ketones with triphenylphosphine are discussed.

We have previously described the reactions of triphenylphosphine with α-bromoacetophenone **1** and with α-bromopropiophenone **2**[3,4] which give the corresponding α-ketophosphonium bromides. We have shown that the Hammett ρ value for the second-order reactions of a series of *meta*- and *para*-substituted α-bromoacetophenones with triphenylphosphine is +0.44 in nitromethane.[5] Such a small positive ρ value is similar to values obtained by us and by previous workers[6,7] for the pyridine–bromoacetophenone system.

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[3] (a) I. J. Borowitz and R. Virkhaus, *J. Amer. Chem. Soc.*, **85**, 2183 (1963); (b) I. J. Borowitz, K. C. Kirby, Jr., and R. Virkhaus, *J. Org. Chem.*, **31**, 4031 (1966).

[4] (a) F. Ramirez and S. Dershowitz, *ibid.*, **22**, 41 (1957); (b) A. V. Dombrovskii and M. I. Shevchuk. *Zh. Obshch. Khim.*, **33**, 1263 (1963).

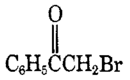
[5] I. J. Borowitz and H. Parnes, *J. Org. Chem.*, **32**, 3560 (1967).

[6] (a) H. H. Jaffé, *Chem. Rev.*, **53**, 206 (1953); (b) A. J. Sisti and S. Lowell, *Can. J. Chem.*, **42**, 1896 (1964).

[7] A. J. Sisti and W. Memeger, Jr., *J. Org. Chem.*, **30**, 2102 (1965).

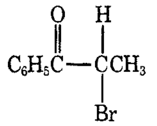
Since the reaction of pyridine with **1** involves displacement of bromide ion, it appears that **1** reacts with triphenylphosphine in a similar manner *in aprotic solvents.*

We have further found that the reaction of triphenylphosphine with **2** is about 280 times slower than with **1**.[8] The nature of the reaction mechanism for the



$C_6H_5\overset{\overset{\displaystyle O}{\|}}{C}CH_2Br$

1

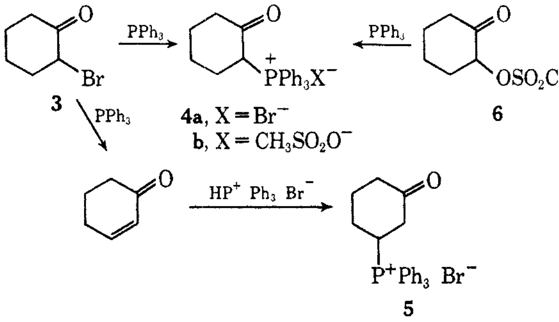


$C_6H_5\overset{\overset{\displaystyle O}{\|}}{C}-\underset{\underset{\displaystyle Br}{|}}{\overset{\overset{\displaystyle H}{|}}{C}}CH_3$

2

triphenylphosphine–**2** system is being investigated kinetically and with the aid of the related reaction with optically active methylphenylpropylphosphine.[9]

2-Bromocyclohexanone **3** reacts with triphenylphosphine to give the 2-ketotriphenylphosphonium salt **4a** in polar solvent and either the 3-ketophosphonium salt **5** or a mixture of **4a** and **5** in nonpolar medium.[3b,10] A mixture of these salts has been previously observed by Hudson from the slow reaction of 2-chlorocyclohexanone with triphenylphosphine.[11] The β-ketophosphonium salt **5** has been postulated as forming *via* an elimination–addition pathway involving cyclohexenone.[3b,10,11]



2-Mesyloxycyclohexanone **6** reacts with triphenylphosphine to give only the corresponding 2-ketophosphonium salt.[3b] The reaction of an α-mesyloxy ketone with triphenylphosphine appears to involve a simple displacement of mesylate ion by the phosphine since there is no product change in the presence of methanol; *i.e.*, there is no conversion into the demesylated ketone.[12]

The difference in behavior for **2** and **3** can be rationalized if **3** reacts more slowly with triphenylphosphine than does **2**. This would be expected if the α-ketophosphonium salts are formed *via* simple displacement of bromide ion in both cases since S$_N$2 displacements are known to be very slow in cyclohexyl systems.[13] The reactions of **3** with triphenylphosphine are complex, however, and there is some evidence that nucleophilic displacement on bromine of **3** by triphenylphosphine is at least partially involved.[3b,10] Regardless of the mechanisms of α-ketophosphonium salt formation for **2** and **3**, it may be that such reaction is slow enough in the case of **3** to allow elimination of hydrogen bromide to occur as a competing reaction.[14]

The hypothesis that hindered α-halo ketones can undergo dehydrohalogenation with triphenylphosphine in aprotic solvents is enforced by our results in the bromoisobutyrophenone system.

Results and Discussion

α-Bromoisobutyrophenone **7** reacts very slowly with triphenylphosphine in benzene at reflux. Reaction in xylene at reflux or without solvent gives the β-keto salt, 2-benzoylpropyltriphenylphosphonium bromide **10a**, and none of the α-ketophosphonium bromide **12a** (Table I). Reaction in acetonitrile, which is more rapid, gives **10a**, isobutyrophenone, and methacrylophenone **11**. Isobutyrophenone could result *via* debromination of unreacted **7** by moisture and triphenylphosphine either in the reaction or during work-up.

TABLE I

THE REACTIONS OF α-BROMOISOBUTYROPHENONE (**7**) WITH TRIPHENYLPHOSPHINE

		Yields, %			
Reaction conditions[a] (at reflux)	Time, hr	β-Ketophosphonium bromide	Isobutyrophenone[b]	**11**[b]	Triphenylphosphine oxide
Dry xylene	20	56			
Neat (60°)	6	80			
Benzene–methanol[c]	23	0	97	0	45
Benzene–methanol	23	0	65	12	83
Dry acetonitrile	21	48	29	13	52

[a] PPh$_3$ (1 equiv) was used unless otherwise indicated. [b] By nmr analysis and isolation. [c] Excess PPh$_3$ (2.3 equiv) was used.

As with other bromo ketones, the initial presence of a protic species such as methanol causes debromination to isobutyrophenone **13** to become the predominant process. Some **11** as well as **13** is formed if only 1 equiv of triphenylphosphine is used, indicating that elimination may compete with debromination in this system.

The β-ketophosphonium bromide **10a** is identified by its nmr spectrum[15] which clearly differentiates it from the α-ketophosphonium salt **12a**. The latter was not present in any of the reactions studied. The β-keto salt **10a** exhibits a multiplet at τ 5.4–6.4 for the methylene and methine protons and two doublets for the methyl group centered at τ 8.35 and 8.45 with J_{HH} = 6.4 and $J_{P^{31}H}$ = 2.3 Hz. Similar four-bond phosphorus proton coupling values of 2.2–2.3 Hz have been observed by Griffin[16] for aromatic protons *ortho* to the methylene group of *p*-methylbenzyltri-*n*-butylphosphonium chloride and *p*-nitrobenzyltriphenylphosphonium chloride.

The structure of **10a** was unambiguously proven by its synthesis as follows. α-Bromoisobutyrophenone

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[8] H. Parnes, research in progress.

[9] (a) O. Korpiun and K. Mislow, *J. Amer. Chem. Soc.*, **89**, 4784 (1967); (b) D. B. Denney and N. G. Adin, *Tetrahedron Lett.*, 2569 (1966); (c) L. Horner and H. Winkler, *ibid.*, 455 (1965).

[10] P. A. Chopard and R. F. Hudson, *J. Chem. Soc.*, 1089 (1966).

[11] P. A. Chopard, R. F. Hudson, and G. Klopman, *ibid.*, 1379 (1965).

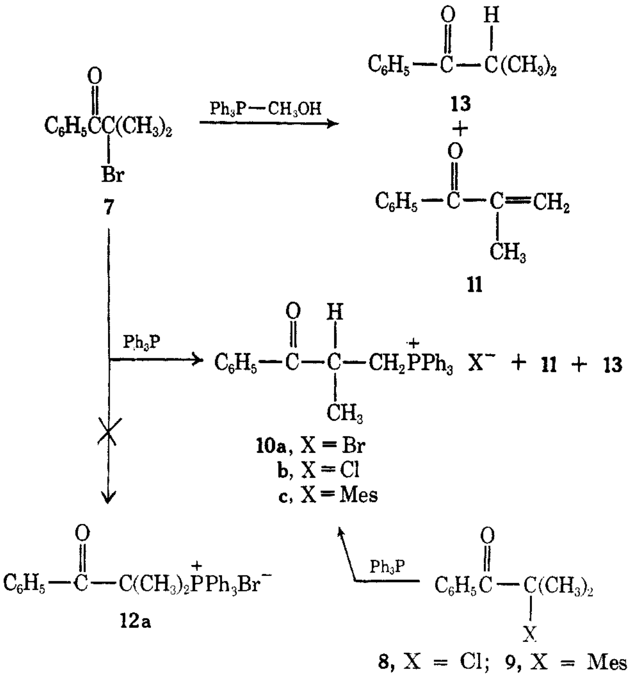
[12] We have demonstrated this for the reaction of benzoin mesylate with triphenylphosphine.

[13] E. L. Eliel, N. L. Allinger, S. J. Angyel, and G. A. Morrison, "Conformational Analysis," John Wiley & Sons, Inc., New York, N. Y., 1965, p 86.

[14] Chopard and Hudson[10] have suggested that **3** is dehydrobrominated by cyclohexanone enolate which was formed by attack on bromine of **3** by triphenylphosphine. There is no evidence for such a pathway in the haloisobutyrophenone reactions.

[15] The nmr spectrum was originally determined for us by Professor C. E. Griffin, University of Pittsburgh.

[16] C. E. Griffin, R. B. Davison, and M. Gordon, *Tetrahedron*, **22**, 561 (1966).

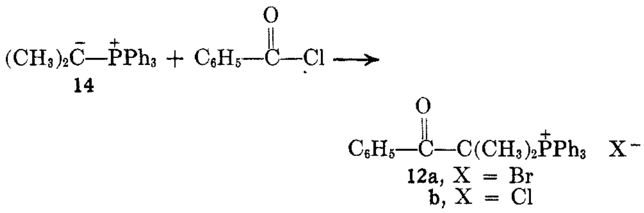


10a, X = Br; **b**, X = Cl; **c**, X = Mes

8, X = Cl; **9**, X = Mes

was dehydrobrominated to **11** with triethylamine and pyridine.[17] Reaction of **11** with triphenylphosphine in the presence of anhydrous hydrogen bromide gave **10a** in 79% yield. A similar addition of triphenylphosphonium hydrobromide to cyclohexenone has been noted.[11] Other additions of triphenylphosphine to double bonds conjugated to electron-withdrawing groups have been demonstrated by Ramirez and by Hoffmann.[18]

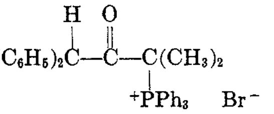
The above synthesis of **10a** strongly suggests that **10a** is formed from **7** and triphenylphosphine *via* the intermediacy of **11**. The possibility that **7** yields the α-ketotriphenylphosphonium bromide **12a** which is unstable and is converted into **11** was also considered. In order to test this possibility **12b** was synthesized (in impure state) from the reaction of isopropylidenetriphenylphosphorane **14** and benzoyl chloride.[19] The nmr spectrum of **12b** exhibits a methyl doublet centered at τ 7.80 with $J_{P^{31}H} = 19$ Hz. The coupling constant is comparable with $J_{PCCH} = 18.7$ Hz for isopropyltriphenylphosphonium bromide and is in the observed range (18.7–20.0) for PCCH coupling.[20]



$$(CH_3)_2\bar{C}-\overset{+}{P}Ph_3 + C_6H_5-\overset{O}{\overset{\|}{C}}-Cl \longrightarrow C_6H_5-\overset{O}{\overset{\|}{C}}-C(CH_3)_2\overset{+}{P}Ph_3\ X^-$$

12a, X = Br
b, X = Cl

The α-ketophosphonium salt **12b** was stable in acetonitrile at reflux for 24 hr, yielding no methacrylophenone **11**. Thus **12a** is probably not an intermediate in the reactions of **7** with triphenylphosphine. A related and apparently stable α-ketotriphenylphosphonium salt **15** has been previously described.[21]



$$(C_6H_5)_2\overset{H}{C}-\overset{O}{\overset{\|}{C}}-C(CH_3)_2 \quad {}^{+}PPh_3\ Br^-$$

15

α-Chloroisobutyrophenone **8** reacts with triphenylphosphine in benzene at reflux for 12 days or in xylene at reflux for 40 hr to give the β-ketophosphonium chloride **10b** in 2 and 80% yields, respectively. No dechlorination occurs if **8** and triphenylphosphine are heated at reflux in methanol. We have previously shown that other α-chloro ketones such as chloroacetophenone or chloropropiophenone give α-ketophosphonium chlorides in reaction with triphenylphosphine whether or not protic species such as methanol were present.[3,22] Our previously described dehalogenation reaction[3,23] occurs mainly with α-bromo ketones and possibly with a few α-chloro ketones.[24]

α-Mesyloxyisobutyrophenone **9** is prepared in 68% yield from the reaction of **7** with silver mesylate.[24b] Reaction of **9** with triphenylphosphine in glyme gives the β-ketophosphonium mesylate **10c** in 77% yield. Thus in the isobutyrophenone system the bromide, chloride, and mesylate all undergo the same elimination–addition sequence. We have found that in other systems the three leaving groups do not give the same product ratios or the same products. Other α-keto mesylates react with triphenylphosphine to give α-ketotriphenylphosphonium salts[24b] while the corresponding α-bromo or chloro ketones give keto- or enoltriphenylphosphonium salts.[3,4,10,22,24b]

The formation of **11** from **7–9** is most likely *via* an E2 elimination of hydrogen bromide, hydrogen chloride, and methanesulfonic acid caused by triphenylphosphine. It is conceivable for **7** and **8**, after some β-ketophosphonium halide has formed, that elimination may be caused, at least in part, by halide ion. Such a possibility is not reasonable, however, for the mesylate reaction since mesylate ion is presumably not basic enough to cause an elimination reaction. Several control experiments indicated that **7** did not eliminate hydrogen bromide upon being heated in acetonitrile, in benzene–methanol, or with triphenylphosphine oxide in benzene–methanol. The elimination of hydrogen halide from a hindered halide by triphenylphosphine has been noted in the case of *sec*-butyl iodide,[25] *t*-butyl chloride,[25] and in several other instances.[26]

In summarizing the reactions of several α-bromo ketones with triphenylphosphine we see a progression of (a) the formation of α-ketophosphonium salts from the unhindered bromoacetophenone and bromopropiophenone systems, (b) some elimination and resultant β-ketophosphonium salt as well as α-ketophosphonium salt formation in the somewhat hindered 2-bromocyclohexanone system, and (c) only β-keto-

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[18] (a) F. Ramirez and S. Dershowitz, *ibid.*, **78**, 5614 (1956); (b) H. Hoffmann, *Chem. Ber.*, **94**, 1331 (1961); (c) F. Ramirez, O. P. Madan, and C. P. Smith, *Tetrahedron Lett.*, 201 (1965).

[19] For a review of the acylation of ylides, see A. W. Johnson, "Ylid Chemistry," Academic Press Inc., New York, N. Y., 1966, pp 45–48.

[20] C. E. Griffin and M. Gordon, *J. Organometal. Chem.*, **3**, 414 (1965).

[21] G. Wittig and A. Haag, *Chem. Ber.*, **96**, 1535 (1963).

[22] K. C. Kirby, Jr., unpublished results.

[23] I. J. Borowitz and L. I. Grossman, *Tetrahedron Lett.*, 471 (1962).

[24] (a) R. Virkhaus, Ph.D. Dissertation, Lehigh University, Bethlehem, Pa., 1965; (b) P. Rusek, unpublished results.

[25] S. Trippett, *Quart. Rev.*, **17**, 406 (1964).

[26] R. F. Hudson, "Structure and Mechanism in Organophosphorus Chemistry," Academic Press Inc., New York, N. Y., 1965, pp 134, 135.

phosphonium salt formation in the hindered haloisobutyrophenone system.

Experimental Section[27]

All of the solvents used were distilled from phosphorus pentoxide, calcium hydride, or lithium aluminum hydride. All reactions were conducted under an atmosphere of dry nitrogen.

α-Bromoisobutyrophenone was prepared by bromination of isobutyrophenone (73%) or purchased from Aldrich. It was distilled through a vacuum-jacketed, silvered, 22-cm Vigreux column: bp 131–134° (15–16 mm) [lit.[28] bp 119–120° (10 mm)].

α-Chloroisobutyrophenone was prepared by the sulfuryl chloride chlorination of isobutyrophenone in 65% yield: bp 74–76° (0.25 mm); one spot (tlc) and one peak (vpc on 20% SE-30).

α-Mesyloxyisobutyrophenone.—A mixture of silver mesylate (5.0 g, 0.025 mol) and α-bromoisobutyrophenone (5.6 g, 0.025 mol) in dry acetonitrile (50 ml) was stirred at room temperature for 4 weeks. After removal of the solvent *in vacuo*, the mixture was treated with hot benzene to leave silver bromide as an insoluble residue. The benzene solution was evaporated *in vacuo*, and the resultant oil was slurried in cyclohexane to give **9** as a solid (4.1 g, 0.017 mol, 68%): mp 90.0–91.0°; ir (CH_2Cl_2), 5.92 (C=O), 7.5 and 8.5 μ (mesylate); nmr ($CDCl_3$), τ 7.17 (s, OSO_2CH_3), 8.13 (s, C—CH_3), and multiplets centered at 2.0 (*o*-phenyl H) and 2.6 (*m,p*-phenyl H). A sample of **9** was recrystallized from cyclohexane for analysis.

Anal. Calcd for $C_{11}H_{14}O_4S$: C, 54.53; H, 5.82; S, 13.23. Found: C, 54.70; H, 5.80; S, 13.16.

The Reaction of α-Bromoisobutyrophenone with Triphenylphosphine. A. In Benzene.—A mixture of α-bromoisobutyrophenone (5.31 g, 0.0234 mol) and triphenylphosphine (6.117 g, 0.0234 mol) in dry benzene (40 ml) was heated at reflux for 22 hr. The supernatant liquid, under nitrogen, was decanted from a small amount of solid into a solution of mercuric chloride (7.0 g, 0.0258 mol) in acetone (30 ml) to give the mercuric chloride–triphenylphosphine complex (9.814 g, 0.0189 mol of 1:1 $HgCl_2$-PPh_3, or a recovery of 88% of triphenylphosphine),[29] mp 306–315°. In other runs the small amount of benzene-insoluble material obtained was shown to be hydroxytriphenylphosphonium bromide. The salt was identified *via* its hydrolysis to triphenylphosphine oxide and its infrared spectrum (EtOH-free $CHCl_3$) which was very similar to that of a genuine sample[3b] and which exhibited peaks at 3.37 (m), 6.94 (s), 8.92 (s), 9.95 (m), and 10.13 (m) μ. A similar reaction of α-bromoisobutyrophenone and triphenylphosphine in deuteriobenzene at 55–60° for 104 hr as followed in a sealed nmr tube gave only a small amount of isobutyrophenone (a doublet centered at τ 8.92 compared with a singlet at 8.15 for **7**).

B. In Xylene.—A mixture of α-bromoisobutyrophenone (1.03 g, 0.0045 mol) and triphenylphosphine (1.232 g, 0.0047 mol) in xylene (15 ml) was heated at reflux for 20 hr to give 2-benzoylpropyltriphenylphosphonium bromide **10a** (1.225 g, 0.0025 mol, 56%). The ir and nmr spectra were identical with those of the genuine salt as described below.

C. In Acetonitrile.—A mixture of α-bromoisobutyrophenone (3.117 g, 0.01375 mol) and triphenylphosphine (3.838 g, 0.01465 mol) in dry acetonitrile (100 ml) was heated at reflux for 21 hr. After distillation of the solvent, the residue was extracted with ethyl acetate to leave a brown insoluble solid which was dissolved in hot ethyl acetate–methylene chloride and treated with charcoal. When the resultant yellow solution was cooled, **10a** crystallized as a white solid (3.21 g, 0.00657 mol, 48%), mp 215–224°. The analytical sample, after three recrystallizations from acetonitrile–ethyl acetate, had mp 223.5–225.5°. *Anal.* Calcd for $C_{28}H_{26}BrOP$: C, 68.72; H, 5.36. Found: C, 68.73; H, 5.08. The ir spectrum of **10a** (CH_2Cl_2) exhibited carbonyl absorption at 5.92 μ and several peaks which are absent in **12** (see below); the nmr spectrum ($CDCl_3$) showed peaks at τ 2.0–2.7 (m, phenyl 5H), 5.4–6.4 (m, CH_2CH-), and two doublets centered at 8.35 and 8.45 (methyl 3 H, J_{HH} = 6.4 Hz, $J_{P^{31}H}$ = 2.3 Hz).

Evaporation of the above mother liquor and evaporation of the original ethyl acetate solution followed by addition of 60–70° petroleum ether gave a combined yield of crude triphenylphosphine oxide (1.99 g, 0.00714 mol, 52%), mp 110–150°, as an insoluble material. Distillation of the petroleum ether solution gave 0.8 g of a 70:30 (nmr integration) mixture of isobutyrophenone and methacrylphenone, bp 110–120° (12 mm). This corresponds to a 29% yield of isobutyrophenone and a 13% yield of methacrylophenone. The infrared spectrum (CCl_4) of the mixture exhibited carbonyl peaks at 5.92 and 6.02 μ; on the gas chromatograph (20% Carbowax on Chromosorb W), **11** appears as a shoulder on the isobutyrophenone peak. The nmr spectrum (CCl_4) showed peaks at τ 8.0 (s, vinyl CH_3 of **11**), 8.85 (d, CH_3 of **13**, J = 6 Hz), 6.5 (m, methine H of **13**), 4.37 (d, C=CH_2 of **11**, J = 15 Hz), and 2.1–2.7 (m, phenyl).

D. No Solvent.—A mixture of α-bromoisobutyrophenone and triphenylphosphine (0.010 mol each) was heated at 80–85° for 6 hr to give **10a** (3.92 g, 0.008 mol, 80%), mp 219–222° (from EtOAc–MeOH).

E. In Benzene–Methanol.—The reaction of **7** (3.00 g, 0.0132 mol) and triphenylphosphine (3.50 g, 0.0133 mol) in a mixture of benzene (40 ml) and methanol (8 ml) at reflux for 23 hr gave methyltriphenylphosphonium bromide (0.64 g, 0.0018 mol, 13%), mp 215–230°, and triphenylphosphine oxide (3.05 g, 0.011 mol, 83%), mp and mmp 154–159° as benzene-insoluble and hexane-insoluble material, respectively. The hexane solution was distilled to give 1.50 g of an 85:15 mixture of isobutyrophenone and methacrylophenone, bp 100–130° (16 mm); the nmr (neat) appeared as reported in C. This corresponds to a 65% yield of **13** and a 12% yield of **11**.

F. In Benzene–Methanol and Excess Triphenylphosphine.—A similar reaction of a mixture of α-bromoisobutyrophenone (2.00 g, 0.0088 mol) and triphenylphosphine (5.23 g, 0.0199 mol) gave isobutyrophenone (1.26 g, 0.00852 mol, 97%), triphenylphosphine oxide (2.46 g, 0.00884 mol, 45%), methyltriphenylphosphonium bromide (2.68 g, 0.00751 mol, 38%), and recovered triphenylphosphine (0.53 g, 0.0020 mol, 10%). Other reactions under similar conditions gave high yields of **13** and of triphenylphosphine oxide (92%).

The Synthesis of Methacrylophenone.—The reaction of α-bromoisobutyrophenone (7.95 g, 0.035 mol) in benzene (25 ml) with dry triethylamine (25 ml) and pyridine (3 ml) at reflux for 48 hr gave **11** (2.55 g, 0.0175 mol, 50%): bp 102–103° (18 mm); ir (CCl_4) 6.01 μ; uv $\lambda_{\max}^{\text{EtOH}}$ 245 mμ; tlc (5% MeOH–C_6H_6), R_f value = 0.56, which is the same as that for isobutyrophenone.

2-Benzoylpropyltriphenylphosphonium Bromide.—Hydrogen bromide gas was slowly bubbled into a mixture of **11** (0.46 g, 0.00315 mol) and triphenylphosphine (0.825 g, 0.00315 mol) in xylene (15 ml) at reflux for 1 hr. The resultant precipitate was washed with benzene to leave 1.429 g of yellow crystals. The colored impurities were extracted with boiling ethyl acetate, and the residual white powder was dried *in vacuo* to give **10a** (1.21 g, 0.00247 mol, 79%): mp 223–227.5°; nmr the same as that given above.

α,α-Dimethylphenacyltriphenylphosphonium Bromide. A. Isopropyltriphenylphosphonium Bromide.—Triphenylphosphine and 2-bromopropane (0.10 mol each) were heated in a sealed Pyrex thick-wall glass tube at 150° for 24 hr. The resultant solid was removed from the tube in methylene chloride and recrystallized from ethanol–ethyl acetate to give isopropyltriphenylphosphonium bromide (34.4 g, 0.089 mol, 89%): mp 238–240° (lit.[30] mp 238–239°); nmr ($CDCl_3$), τ 7.8 (m, phenyl), 8.80 and 8.48 (d, CH_3, J_{HH} = 7 Hz, $J_{P^{31}H}$ = 19 Hz), and *ca.* 4.5 (m, methine H).

B. Formation of Isopropylidenetriphenylphosphorane and Reaction with Benzoyl Chloride.—The addition to a suspension of isopropyltriphenylphosphonium bromide (4.95 g, 0.0129 mol) in ether (*ca.* 30 ml) of three portions of phenyllithium[31] in ether (*ca.* 0.010 mol each) gave a red mixture. The solid was allowed to settle, and the resultant red solution was decanted under nitrogen into a solution of benzoyl chloride (2–3 equiv) in ether to give solid **12**, mp 220–230°, as a mixture of phosphonium bromide and chloride: ir (CH_2Cl_2), 6.00, 10.40, and the absence of peaks at 10.25, 11.00 and 11.80 μ (all of which are present in the ir spectrum of **10a**); nmr ($CDCl_3$), τ 2.2 (m, 20 phenyl H) and 7.90 (d, 6 methyl H, $J_{P^{31}H}$ = 19 Hz). Attempts to purify the salt to an analytically pure stage were unsuccessful.

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[27] The instrumental and other techniques used have been recorded previously.[3b]

[28] J. H. Boyer and D. Straw, *J. Amer. Chem. Soc.*, **75**, 1643 (1953).

[29] We have previously obtained this complex in 1:1 stoichiometry.[3b]

[30] U. H. M. Fagerlund and D. R. Idler, *ibid.*, **79**, 6473 (1957).

[31] A 20% solution of phenyllithium in benzene–ether from Foote Mineral Co. was employed.

C. Stability of 12.—A solution of **12** in acetonitrile was heated for 3 hr. Distillation of the solvent plus possible volatile components gave a distillate which was only acetonitrile by vpc. The residue was heated at reflux in fresh acetonitrile for 24 hr and evaporated to leave a new residue with an nmr spectrum which was identical with that of **12**.

The Reaction of α-Chloroisobutyrophenone with Triphenylphosphine. A. In Benzene or Xylene.—A mixture of **8** and triphenylphosphine (0.028 mol each) in benzene (25 ml) was heated at reflux for 12 days to give 2-benzoylpropyltriphenylphosphonium chloride **10b** (0.305 g, 0.0006 mol, 2%): mp 229–232°; ir (CH_2Cl_2), very similar to that of the corresponding bromide **10a**. The remaining solution contained starting compounds and triphenylphosphine oxide (by tlc). A mixture of **8** and triphenylphosphine (0.0158 mol each) in xylene (15 ml) was heated at reflux for 40 hr to give **10b** (5.64 g, 0.0126 mol, 80%), ir and nmr spectra as above. Addition of mercuric chloride in ethanol to the residual solution gave $(C_6H_5)_3P\cdot HgCl_2$ (1.56 g, 0.03 mol, 19%).

B. In Methanol.—A mixture of **8** and triphenylphosphine (0.021 mol each) in methanol (40 ml) was heated at reflux for 3 days to give no **10b** nor isobutyrophenone. Much triphenylphosphine was left (precipitate with mercuric chloride).

The Reaction of α-Mesyloxyisobutyrophenone 9 with Triphenylphosphine.—A solution of mesyloxyisobutyrophenone[24b] (1.51 g, 0.0062 mol) and triphenylphosphine (1.61 g, 0.0062 mol) in dry glyme (25 ml, distilled from $LiAlH_4$) was heated at reflux for 6 days. Triphenylphosphine was now absent (negative mercuric chloride test). 2-Benzoylpropyltriphenylphosphonium mesylate was formed as an insoluble precipitate (2.41 g, 0.0048 mol, 77%), mp 178.5–179.5° (recrystallized from glyme). The ir spectrum (CH_2Cl_2) exhibited peaks at 5.92 (C=O) and 8.2–8.4 μ (mesylate anion). The nmr spectrum ($CDCl_3$) exhibited peaks as those for **10a** (above) and a singlet at τ 7.32 (OSO_2CH_3).

Control Experiments. A. The Stability of α-Bromoisobutyrophenone.—No methacrylophenone was formed, and **7** was recovered unchanged (by tlc) after it was heated at reflux in acetonitrile solution (24 hr), in benzene–methanol solution (5:1 v/v, 24 hr), or in a solution of triphenylphosphine oxide in 5:1 benzene–methanol (24 hr).

B. 2-Benzoylpropyltriphenylphosphonium Bromide.—A solution of **10a** (0.502 g) in methanol (10 ml) was heated at reflux for 24 hr. No compounds other than **10a** were detected by tlc. Evaporation of the solvent left a solid (0.51 g), mp 217–224°, whose ir (CH_2Cl_2) spectrum was identical with that of genuine **10a**.

Registry No.—Triphenylphosphine, 603-35-0; **9**, 17231-17-3; **10a**, 17730-94-8; **10c**, 17730-97-1; **11**, 769-60-8; **12a**, 17730-95-9; **12b**, 17730-96-0; **13**, 611-70-1.

The Reaction of Diethyl Phosphonate with Methyl and Ethyl Grignard Reagents

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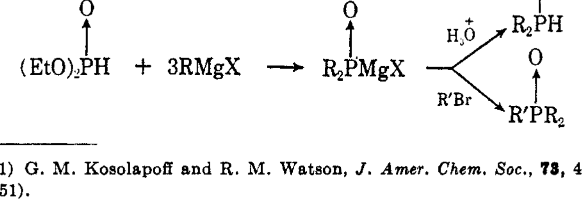
The reaction of diethyl phosphonate with methyl and ethyl Grignard reagents has been investigated. Chemical and physical evidence suggest that the intermediate (I) is not a diethoxyphosphinylmagnesium halide [$(RO)_2P(\rightarrow O)MgX$] but is a trivalent phosphorus species [$(RO)_2\ddot{P}OMgX$]. The latter undergoes rapid substitution with methyl Grignard reagent at 25° to give the halomagnesium dimethyl- and diethylphosphinites ($R_2\ddot{P}OMgX$), II and III, respectively. Phosphorus nmr spectra suggest that the phosphorus atom in the phosphinites (II and III) is also best represented as a trivalent species. Hydrolysis of the phosphinites (II and III) with aqueous potassium carbonate gave aqueous solutions of the hitherto unknown dimethylphosphine oxide and diethylphosphine oxide, respectively. Contrary to previous reports, these secondary phosphine oxides are sufficiently stable to be isolated in good yields by careful distillation. Their structures were confirmed by infrared and proton and phosphorus nmr spectra, and by several of their reactions. Alkylation of the phosphinites (II and III) in tetrahydrofuran produced tertiary phosphine oxides in good yields. These findings demonstrate that the reaction of diethyl phosphonate with Grignard reagents is a useful and general synthesis of both secondary and tertiary phosphine oxides.

Diethyl phosphonate and alkyl or aryl Grignard reagents have been used extensively to prepare secondary phosphine oxides[1–4] and unsymmetrical tertiary phosphine oxides.[5–7] However, attempts to prepare the lower molecular weight dialkylphosphine oxides (C_1–C_4) by this procedure were unsuccessful, reportedly because of their instability.[2] Possibly for this reason only higher alkyl Grignard reagents have been used in the synthesis of trialkylphosphine oxides.[6] To determine the generality of this route to secondary and tertiary phosphine oxides, the reaction of diethyl phosphonate with methyl and ethyl Grignard reagents was investigated.



$$(EtO)_2\overset{O}{\overset{\uparrow}{P}}H + 3RMgX \longrightarrow R_2\overset{O}{\overset{\uparrow}{P}}MgX \begin{cases} \xrightarrow{H_3\overset{+}{O}} R_2\overset{O}{\overset{\uparrow}{P}}H \\ \xrightarrow{R'Br} R'\overset{O}{\overset{\uparrow}{P}}R_2 \end{cases}$$

Results

The over-all reaction of diethyl phosphonate with 3 equiv of methylmagnesium chloride is rapid and quite exothermic. An ice bath is required to maintain a temperature of 25–30°. That the reaction is relatively fast is evident from the fact that reaction times longer than 1–2 hr did not significantly increase the yield of dimethylphosphine oxide (Table I). Furthermore, only 30–34% yields of methane were obtained when 1 equiv of diethyl phosphonate was added to methylmagnesium chloride in tetrahydrofuran (THF).[8] In the latter case a 62% yield of dimethyl-

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[1] G. M. Kosolapoff and R. M. Watson, *J. Amer. Chem. Soc.*, **73**, 4101 (1951).

[2] (a) R. H. Williams and L. A. Hamilton, *ibid.*, **74**, 5418 (1952); **77**, 3411 (1955). (b) R. C. Miller, J. S. Bradley, and L. A. Hamilton, *ibid.*, **78**, 5299 (1956).

[3] B. B. Hunt and B. C. Saunders, *J. Chem. Soc.*, 2413 (1957).

[4] M. Grayson, C. E. Farley, and C. A. Streuli, *Tetrahedron*, **23**, 1065 (1967).

[5] J. J. Richard and C. V. Banks, *J. Org. Chem.*, **28**, 123 (1963).

[6] (a) T. H. Siddall, III, and M. A. Davis, *J. Chem. Eng. Data*, **10**, 303 (1965). (b) A recent article claims that the procedure in ref 6a is unsatisfactory for the preparation of alkyldimethylphosphine oxides. See H. M. Priestley, *ibid.*, **12**, 618 (1967).

[7] I. M. Downie and G. Morris, *J. Chem. Soc.*, 5771 (1965).

[8] A. N. Pudovik, *Zh. Obshch. Khim.*, **22**, 109 (1952); *Chem. Abstr.*, **46**, 11099 (1952). Ethane was obtained in 30–32% yields upon straight addition of diethyl phosphonate to ethylmagnesium bromide.