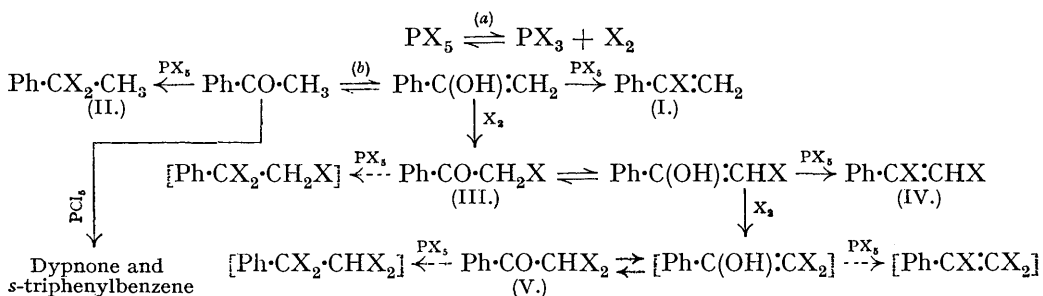


63. The Action of Phosphorus Pentahalides on Acetophenone.

By WILLIAM TAYLOR.

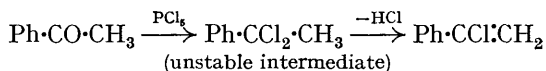
AN attempt to prepare $\alpha\alpha$ -dibromoethylbenzene, required for kinetic purposes, by adding acetophenone to phosphorus trichlorodibromide gave a liquid having almost the required bromine content. Preliminary kinetic experiments with alcoholic potassium hydroxide, however, revealed a non-equivalent rapid reaction, followed by a much slower halogen elimination. Oxidation of the liquid with alkaline permanganate gave benzoic acid alone and therefore the slowly reacting halogen was not nuclear. End-product experiments yielded no acetophenone or its acetal and the only product identified was a small amount of a mixture of the α - and the β -form of "bromodiphenacyl." This had previously been obtained from ω -bromoacetophenone (*e.g.*, Fritz, *Ber.*, 1895, 28, 3088; Paal and Demeler, *Ber.*, 1896, 29, 2093) and its formation suggested that ω -bromoacetophenone was present in the liquid. When phosphorus trichlorodibromide was added to well-cooled acetophenone, the product was mainly ω -bromoacetophenone.

At this point it was decided to examine more closely the action of phosphorus pentahalides, and especially of the chlorobromide, on acetophenone. The results can be summarised and interpreted by the following scheme:



Compounds and reactions indicated by dotted lines were not realised in practice. Two feasible assumptions have been made, namely, that halogen substitution for ketonic oxygen or for hydroxyl is effected by the pentahalide (in preference to the trihalide while the former

is still present), and that halogen addition to the enolic form is effected by free halogen (followed by the elimination of hydrogen halide). The main evidence on which the scheme is based is the isolation or identification of compounds of types (I), (II), (III), (IV), and (V), but further support is given by the following considerations. The proportion of (III) formed relative to (I) and (II) will be governed mainly by the equilibria (*a*) and (*b*): these are both affected by temperature, and (*b*) by the presence of acid (HX) also. However, the effect of (*b*) will be more or less constant, because acetophenone is always one of the two reagents. On the other hand the nature of the reagent PX_5 varies with the nature of X, and with this will vary the position of (*a*). Thus one need only discuss the effect of (*a*). At any temperature the degree of dissociation of the trichlorodibromide will be greater than that of the pentachloride, and hence one would expect that at relatively low temperatures the proportion of (III) produced by the former would be greater than that produced by the latter. This is in agreement with practice, for, whilst the main product with phosphorus chlorobromide was ω -bromoacetophenone (III), Friedel (*Compt. rend.*, 1868, **67**, 1192) and the present author obtained only α -chlorostyrene (I) and $\alpha\alpha$ -dichloroethylbenzene (II) with phosphorus pentachloride. The scheme now presented differs materially from the one advocated by the earlier investigators (cf. Dyckerhoff, *Ber.*, 1877, **10**, 120) and still quoted (*e.g.*, Francis, "Notes on Organic Chemistry," 1935, p. 322):



It would appear that the instability previously attributed to the "keto-halides" of acetophenone is due to the *simultaneous* and not subsequent formation of α -halogenostyrene.

The products formed by adding acetophenone to well-cooled phosphorus chlorobromide were mainly ω -bromoacetophenone and $\alpha\beta$ -dibromostyrene, together with $\omega\omega$ -dibromoacetophenone and $\alpha\alpha$ -dibromoethylbenzene in smaller amounts. In all probability α -bromostyrene also was formed, but was reconverted into acetophenone during the subsequent treatment (Ashworth and Burkhardt, *J.*, 1928, 1791, have shown its almost instantaneous transformation into acetophenone by boiling formic acid). Kröhnke (*Ber.*, 1936, **69**, 921) found that the difficulty in preparing $\omega\omega$ -dibromo- and $\omega\omega\omega$ -tribromoacetophenone from bromine and acetophenone was due to the ready reduction of these compounds by acetophenone in the presence of hydrogen bromide. This affords an explanation of the small amount of di- relative to mono-bromoacetophenone produced under the conditions of the present experiments with phosphorus chlorobromide, especially when this is added to acetophenone and not vice versa. Excess of phosphorus chlorobromide gave with ω -bromoacetophenone a mixture of $\omega\omega$ -dibromoacetophenone and $\alpha\beta$ -dibromostyrene. Phosphorus pentabromide reacted vigorously with acetophenone to give much carbon and traces only of ω -bromoacetophenone. Phosphorus pentachloride and acetophenone yielded $\alpha\alpha$ -dichloroethylbenzene and α -chlorostyrene (compare Friedel, *loc. cit.*). Phosphorus pentachloride, or the hydrogen chloride liberated in the reaction, acted also as a condensing agent, for in one experiment, acetophenone and the pentachloride being in contact for many hours at room temperature, dypnone was formed (compare Béhal, *Bull. Soc. chim.*, 1888, **50**, 632; Dyckerhoff, *loc. cit.*).

EXPERIMENTAL.

Preparations.— $\alpha\beta$ -Dibromostyrene obtained from phenylacetylene (Hessler, "Organic Syntheses," 1922, **2**, 67) by addition of bromine (Nef, *Annalen*, 1899, **308**, 223) had b. p. 136—138°/17 mm. (Nef gives b. p. 132—135°/15 mm.).

ω -Bromoacetophenone prepared by Rather and Reid's method (*J. Amer. Chem. Soc.*, 1919, **41**, 75) had b. p. 138—139°/14 mm., m. p. 50° (Clibbens and Nierenstein, *J.*, 1912, **107**, 1492, give b. p. 135°/18 mm.).

$\omega\omega$ -Dibromoacetophenone was prepared from acetophenone (20 g.) in glacial acetic acid (25 c.c.) at 35—40° by the addition of bromine (60 g.) in glacial acetic acid (30 c.c.) during 15 minutes. After being left at room temperature for 1½ hours, the liquid was poured into ice-water (500 c.c.), and the product crystallised from methylated spirit (40 c.c.); yield 25 g., b. p. 159—160°/13 mm., m. p. 36—37° (Evans and Parkinson, *J. Amer. Chem. Soc.*, 1913, **35**, 1771, give b. p. 175—176°/23 mm.) (Found: Br, 57.6. Calc.: Br, 57.6%).

Reaction between Acetophenone and Phosphorus Chlorobromide.—Acetophenone (60 g.) was added (about 2 drops per sec.) with shaking during 1 hour to phosphorus chlorobromide (150 g.), surrounded by ice-water; there was a vigorous evolution of hydrogen bromide and the temperature never rose above 5°. The liquid was then heated at 40° for $\frac{1}{4}$ hour, cooled, added to ice (500 c.c.), left 1 hour, and extracted with ether. Five fractions were obtained by distillation: (1) 10.8 g., b. p. 80—90°/15 mm. (Found: Br, 15.9%); (2) 8.6 g., b. p. 90—105°/15 mm. (Found: Br, 21.3%); (3) 11.5 g., b. p. 105—125°/15 mm. (Found: Br, 31.4%); (4) 21.5 g., b. p. 125—135°/12 mm. (Found: Br, 53.7%); (5) 23.5 g., b. p. 135—158°/12 mm. (Found: Br, 59.3%). Much tar was left, but no dypnone. A little of fraction (5), collected separately when the b. p. was constant at 155°/9 mm. or 153°/8 mm. (Found: Br, 57.6. Calc. for $C_8H_6OBr_2$: Br, 57.6%), crystallised in ice-salt; it melted, however, at room temperature and therefore was not pure $\omega\omega$ -dibromoacetophenone. 20 G. of fraction (5) were redistilled and gave three fractions: (5L) 3.3 g., b. p. 100—124°/18 mm., (5I) 12.3 g., b. p. 134—156°/18 mm., (5U) 3.8 g., b. p. 156—168°/18 mm. and finally constant at 168°/18 mm. The separation by fractionation was very incomplete, since all the fractions contained acetophenone and ω -bromoacetophenone, as shown below.

Examination of the Fractions for Acetophenone.—A portion of the fraction was dissolved in methylated spirit (30 c.c.) and water (10 c.c.) containing semicarbazide hydrochloride (1.2 g.) and sodium acetate (1.2 g.) and maintained at 55° for 5 hours; water (200 c.c.) was then added:

| Fraction | (1) | (2) | (3) | (4) | (5L) |
|---------------------------------------|-------|-------|-------|-------|-------|
| Wt. taken (g.) | 1.287 | 1.247 | 1.689 | 2.329 | 1.205 |
| Wt. of crude semicarbazone (g.) | 1.130 | 0.974 | 0.575 | 0.101 | 0.004 |

When the crude semicarbazones were separately recrystallised from methylated spirit, there was only slight loss in weight and the products had m. p.'s ranging from 190 to 195°. ω -Bromoacetophenone (1.5 g.), treated in exactly the same way as the fractions, gave a resinous solid (0.24 g.), m. p. 60—105° (ω -bromoacetophenone has m. p. 50°, and its semicarbazone has m. p. 146°; Knöpfer, *Monatsh.*, 1926, 119, 145).

Examination of the Fractions for ω -Bromoacetophenone.—A portion of the fraction was dissolved in ethyl alcohol (50 c.c.) at 55°, succinic acid (1.5 g.) and sodium carbonate (1.1 g.) in water (5 c.c.) added, and the liquid maintained at 55° for 20 hours; the solid obtained was washed with water to remove sodium bromide:

| Fraction | (1) | (2) | (3) | (4) | (5L) |
|-----------------------------|-------|-------|-------|-------|-------|
| Wt. taken (g.) | 1.527 | 1.446 | 1.221 | 1.274 | 0.608 |
| Wt. of succinate (g.) | 0.006 | 0.010 | 0.074 | 0.081 | 0.006 |

The m. p. of the phenacyl succinate was 148° in every case. Fractions (3) and (4) were thus shown to contain much ω -bromoacetophenone.

$\omega\omega$ -Dibromoacetophenone, when similarly treated with sodium succinate, gave an oil but no crystalline solid. To show that phenacyl succinate could be prepared from ω -bromoacetophenone in presence of $\omega\omega$ -dibromoacetophenone and $\alpha\beta$ -dibromostyrene, succinic acid (1.5 g.) and sodium carbonate (1.1 g.) in water (5 c.c.) were added to a hot solution of ω -bromoacetophenone (0.5 g.), $\omega\omega$ -dibromoacetophenone (2.8 g.), and $\alpha\beta$ -dibromostyrene (5.4 g.) in ethyl alcohol (50 c.c.) and the whole was refluxed for 3 hours. The liquid was cooled and filtered, and the solid washed four times with ethyl alcohol (5 c.c.) and thrice with water (5 c.c.); the crystalline solid obtained (less than 0.1 g.) had m. p. 148° (Rather and Reid, *loc. cit.*, give m. p. 148°).

Examination of Fraction (5I) for $\alpha\beta$ -Dibromostyrene.—Kinetic experiments showed that both mono- and di-bromoacetophenone suffered a rapid elimination of bromine at 25° on treatment with alcoholic potash, but that freshly prepared $\alpha\beta$ -dibromostyrene suffered only a slow elimination. The method of separation therefore consisted in destruction of the first two compounds by alcoholic potash at room temperature and distillation of the low-boiling products from the higher-boiling $\alpha\beta$ -dibromostyrene.

A solution of fraction (5I) in ethyl alcohol (100 c.c.) at room temperature was shaken for $\frac{1}{2}$ minute with 2*N*-alcoholic potash (20 c.c.), 2*N*-hydrochloric acid (20 c.c.) promptly added, and the liquid immediately poured into water (1 l.) and extracted with ether. On distillation, two fractions were obtained, (a) 4.0 g., b. p. 95—134°/17 mm., (b) 5.0 g., b. p. 135—138°/17 mm., and some tar. Fraction (b) (Found: Br, 60.9. Calc. for $C_8H_6Br_2$: Br, 61.0%), like authentic $\alpha\beta$ -dibromostyrene, became slightly cloudy and evolved hydrogen bromide on exposure to air for some time.

Examination of Fraction (5U) for $\omega\omega$ -Dibromoacetophenone.—A solution of fraction (5U) (3.8 g.) in methyl alcohol (75 c.c.) was mixed with hydroxylamine hydrochloride (6.0 g.) in

2*N*-sodium hydroxide (25 c.c.), and the acid liquid maintained at a moderate temperature for 6 hours, at room temperature for 24 hours, and then extracted with ether. Distillation of the ether from the extract left a white solid; this, crystallised from benzene, gave a solid (0.42 g.), m. p. 162° (Strassmann, *Ber.*, 1889, 22, 419, gives m. p. 162° for "anti-phenylamphiglyoxime"). Addition of ligroin to the benzene filtrate yielded a further 0.20 g. of impure solid, m. p. 150° (Schramm, *Ber.*, 1885, 18, 353, gives m. p. 152° for the amorphous solid precipitated in this way). ω -Bromoacetophenone (1.0 g.), treated in an identical way, gave, on distillation of the ether, a thick oil which developed a surface film on cooling but from which no solid could be isolated. Hence this compound was not responsible for the formation of anti-phenylamphiglyoxime above.

Examination of Fraction (3) for $\alpha\alpha$ -Dibromoethylbenzene.—This fraction became cloudy very quickly on exposure to air, whereas all the other original fractions remained clear. Bromine was displaced in dry alcohol alone. The time of displacement of half the replaceable bromine at 55° was 6.0 minutes, which agrees closely with the time of half-reaction of $\alpha\alpha$ -dibromoethylbenzene in dry alcohol, namely, 6.2 minutes ($k_{\text{uni.}} = 0.112 \text{ min.}^{-1}$). The procedure was to add 10 c.c. of the reaction mixture to 25 c.c. of benzene and 50 c.c. of water and titrate the liberated acid with *N*/10-sodium hydroxide. The weight of the fraction in dry ethyl alcohol (50 c.c.) was 1.6275 g., and the temperature 55°.

| | | | | | | |
|----------------|------|------|------|------|------|------|
| <i>t</i> | 0 | 5.2 | 10.5 | 21.5 | 42.0 | 67.5 |
| Titre..... | 0.10 | 0.58 | 0.90 | 1.10 | 1.16 | 1.15 |

This would give a percentage of 4.3 of $\alpha\alpha$ -dibromoethylbenzene in fraction (3). A much smaller proportion was found in (5L).

Preparation of ω -Bromoacetophenone from Phosphorus Chlorobromide and Acetophenone.—Phosphorus chlorobromide (160 g.) was added in small quantities with constant shaking to acetophenone (50 g.) cooled in ice-water; the temperature never exceeded 5°. After decomposition of the phosphorus compounds by ice-water the liquid was extracted with ether. Removal of the ether from the extract at room temperature left a thick pulp of crystals. By filtration and recrystallisation from ethyl alcohol a solid (27 g.) was obtained, m. p. and mixed m. p. with ω -bromoacetophenone 50° (Found: Br, 40.4. Calc.: Br, 40.2%), oxidation of which with alkaline permanganate yielded benzoic acid (m. p. and mixed m. p.). The filtrate (20 g.) gave three fractions on distillation: (1) 3.5 g. (semicarbazone, m. p. 195°), b. p. 80—131°/15 mm. (Found: Br, 16.4%); (2) 10.5 g., b. p. 131—136°/15 mm. (Found: Br, 44.3%), contained ω -bromoacetophenone, b. p. 134°/15 mm., m. p. and mixed m. p. 50°; (3) 3.0 g., b. p. 136—145°/15 mm. (Found: Br, 54.3%), probably a mixture of mono- and di-bromoacetophenones and $\alpha\beta$ -dibromostyrene.

Action of Phosphorus Chlorobromide on ω -Bromoacetophenone.—Phosphorus chlorobromide (32 g., *i.e.*, a large excess) was added all at once to ω -bromoacetophenone (7 g.) and the temperature was maintained at 20° for 15 minutes; there was a vigorous evolution of hydrogen bromide. The temperature was raised to 55° for 5 minutes, and the liquid then left at room temperature for 2 hours. After the usual water-ether treatment a liquid (7.0 g.), b. p. 131—146°/10 mm. (Found: Br, 58.7%), was obtained. On redistillation two fractions were separated: (1) 2.8 g., b. p. 130—137°/8 mm. (Found: Br, 59.5%); (2) 4.0 g., b. p. 138—142°/7 mm. (Found: Br, 57.5. Calc. for $\text{C}_8\text{H}_6\text{OBr}_2$: Br, 57.6%). Fraction (1) was probably mainly $\alpha\beta$ -dibromostyrene (Calc.: Br, 61.0%) with some dibromoacetophenone. Fraction (2), cooled in ice-salt, gave crystals, m. p. 35—36° alone or mixed with authentic $\omega\omega$ -dibromoacetophenone.

Action of Phosphorus Pentachloride on Acetophenone.—Experiment I. Acetophenone (60 g.) was added to phosphorus pentachloride (105 g.) at 15°. The temperature rose to 75° in 10 minutes, a vigorous evolution of hydrogen chloride taking place, and then fell to 50°, the evolution becoming slow; the reaction was apparently completed in 20 minutes at 70°. After the usual water-ether treatment, distillation gave four fractions: (1) 27.5 g., b. p. 80—86°/17 mm. (Found: Cl, 15.9%); (2) 22.2 g., b. p. 86—88°/17 mm. (Found: Cl, 16.0%); (3) 4.0 g., b. p. 88—90°/18 mm. (Found: Cl, 16.0%); (4) 3.0 g., b. p. 90—105°/20 mm. (Found: Cl, 12.2%). There was some residual tar. All the fractions fumed, but were not lachrymatory; they were examined for acetophenone as in the chlorobromide experiments (p. 306):

| | | | | |
|---------------------------------------|-------|-------|-------|-------|
| Fraction | (1) | (2) | (3) | (4) |
| Wt. taken (g.)..... | 1.131 | 1.343 | 0.361 | 0.708 |
| Wt. of crude semicarbazone (g.) | 0.560 | 0.970 | 0.659 | 0.475 |

Recrystallisation of the crude semicarbazone from methylated spirit had a result similar to that in the chlorobromide experiments. From the b. p.'s (cf. ω -chloroacetophenone, b. p. 244°), chlorine contents, and weights of semicarbazone, it appeared that the fractions contained α -chlorostyrene. In an attempt to isolate α -chlorostyrene, after filtration of the semicarbazone from fraction (1), an oil (0.3 g.) was obtained which had Cl, 15.2%. The separation therefore was not satisfactory. Fraction (4) was examined for $\alpha\alpha$ -dichloroethylbenzene in a manner similar to that for $\alpha\alpha$ -dibromoethylbenzene (p. 307) at 55°; the weight of the fraction in dry ethyl alcohol (50 c.c.) was 1.0900 g.:

| | | | | | |
|----------------|------|------|------|------|------|
| <i>t</i> | 0 | 34 | 105 | 343 | 1380 |
| Titre..... | 0.90 | 1.20 | 1.60 | 1.90 | 1.90 |

From these figures the time of displacement of half the replaceable chlorine was 64 minutes, which approximates to the time of half-reaction of $\alpha\alpha$ -dichloroethylbenzene in dry ethyl alcohol, namely, 53 minutes ($k_{\text{uni.}} = 0.0131 \text{ min.}^{-1}$). This compound therefore was probably present to the extent of 4% in fraction (4).

Experiment II. Phosphorus pentachloride (40 g.) was added with shaking to acetophenone (20 g.), cooled in ice-water, during 10 minutes. There was little or no evolution of hydrogen chloride and the liquid was left overnight at room temperature. After the usual water-ether treatment, three fractions were obtained: (1) 19 g., b. p. 79–82°/10 mm. (Found: Cl, 9.6%); (2) 3 g., b. p. 82–110°/10 mm. (Found: Cl, 5.9%); (3) 4 g., b. p. 203–204°/10 mm. (Found: Cl, 0). Fractions (1) and (2) contained acetophenone, and probably some α -chlorostyrene; 5 g. of (1) yielded 5 g. of acetophenonesemicarbazone, and 3 g. of (2) gave 3.4 g. of this semicarbazone. (3) was dypnone (Found: C, 86.6; H, 6.7. Calc. for $\text{C}_{16}\text{H}_{14}\text{O}$: C, 86.5; H, 6.3%).

Action of Phosphorus Pentabromide on Acetophenone.—Phosphorus pentabromide (95 g.) was added during 1 hour to acetophenone (26 g.); the temperature was mainly 15° and never exceeded 17° and the evolution of hydrogen bromide could be stopped immediately by immersion of the reaction flask in ice-water. The liquid was left at room temperature for 2 hours. After the usual water-ether treatment two fractions were obtained, both being dark brown, viscous, fuming liquids: (1) 2.6 g., b. p. 50–80°/30 mm. (Found: Br, 34.6%); (2) 5.1 g., b. p. 80–95°/21 mm. (Found: Br, 26.1%). The main product, however, was a non-volatile thick tar, from which chloroform extracted nothing that could be crystallised. Fractions (1) and (2), examined for ω -bromoacetophenone, gave the following yields of phenacyl succinate:

| | | |
|-----------------------------|-------|-------|
| Fraction | (1) | (2) |
| Wt. taken (g.)..... | 0.763 | 1.942 |
| Wt. of succinate (g.) | 0.005 | 0.015 |

Traces of sodium bromide were present in both specimens of succinate. Examination for acetophenone as before showed that the fractions mainly consisted of this compound:

| | | |
|---------------------------------------|-------|-------|
| Fraction | (1) | (2) |
| Wt. taken (g.)..... | 0.761 | 1.493 |
| Wt. of crude semicarbazone (g.) | 0.212 | 1.063 |

SUMMARY.

1. The action of a phosphorus pentahalide (PCl_5 , PCl_3Br_2 , PBr_5) on acetophenone yields a variety of products.

2. The formation of these products is probably due to the existence of the keto-enol equilibrium system (acetophenone) and the thermal equilibrium system of the phosphorus halide.

3. By assuming (a) that halogen substitution for carbonyl oxygen or for hydroxyl proceeds by the action of the phosphorus halide, and (b) that halogen addition occurs owing to the presence of free halogen, the results can be interpreted.