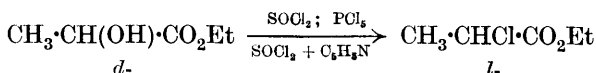


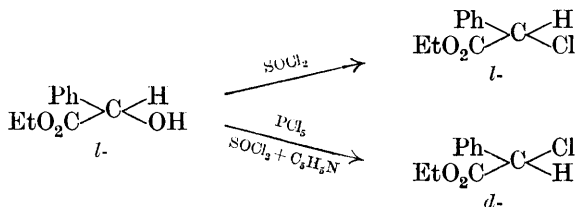
LII.—*The Halogenation of Optically Active Phenyl-methylcarbinol in the Presence and in the Absence of Pyridine, by Thionyl Chloride and the Chlorides and Oxichloride of Phosphorus.*

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In the presence and also in the absence of pyridine, the action of thionyl chloride on optically active aliphatic hydroxy-compounds (*e.g.*, ethyl *d*-lactate, Frankland and Garner, J., 1914, **105**, 1101; *l*- $\beta$ -octanol, Levene and Mikeska, *J. Biol. Chem.*, 1924, **59**, 45; McKenzie and Tudhope, *ibid.*, 1924, **62**, 551) is accompanied by a change in the sign of rotation.



The action of phosphorus pentachloride on ethyl *d*-lactate (Purdie and Williamson, J., 1896, **69**, 820) also leads to a change of sign of rotation. Towards compounds containing a phenyl group directly attached to the asymmetric carbon atom, the behaviour of phosphorus trichloride and phosphorus pentachloride is similar to their behaviour towards the purely aliphatic compounds. On the other hand, the behaviour of thionyl chloride towards the semi-aromatic compounds differs from that of the chlorides of phosphorus and also from its own behaviour towards aliphatic compounds, since with the semi-aromatic compounds (*e.g.*, ethyl *l*-mandelate, McKenzie and Clough, J., 1910, **97**, 2564; McKenzie and Barrow, J., 1911, **99**, 1910) it yields products with the same sign of rotation.



It has been shown, however, that in the presence of pyridine and other tertiary bases, the action of thionyl chloride on ethyl *l*-mandelate leads to a result similar to that obtained when phosphorus pentachloride is used (Kenyon, Lipscomb, and Phillips, J., 1930, 415).

Since the substantiation and extension of these results is obviously

desirable, the halogenation of *l*-phenylmethylcarbinol by thionyl chloride, the chlorides and oxychloride of phosphorus in the presence and in the absence of pyridine has now been studied. The results of the investigation are summarised in Table I. For purposes of comparison the sign and magnitude of rotation of the  $\alpha$ -chloroethylbenzene obtained by the action of hydrogen chloride (Pickard and Kenyon, J., 1911, 99, 45) and of thionyl chloride and phosphorus trichloride (McKenzie and Clough, *loc. cit.*) on *l*-phenylmethylcarbinol have been incorporated in this table, the specific rotatory powers ( $[\alpha]_{5461}$ ) of the products obtained by these authors having been calculated from the recorded values ( $[\alpha]_{5893}$ ) by aid of the dispersion ratio,  $\alpha_{5893}/\alpha_{5461} = 0.810$ , which has been determined for this purpose.

TABLE I.

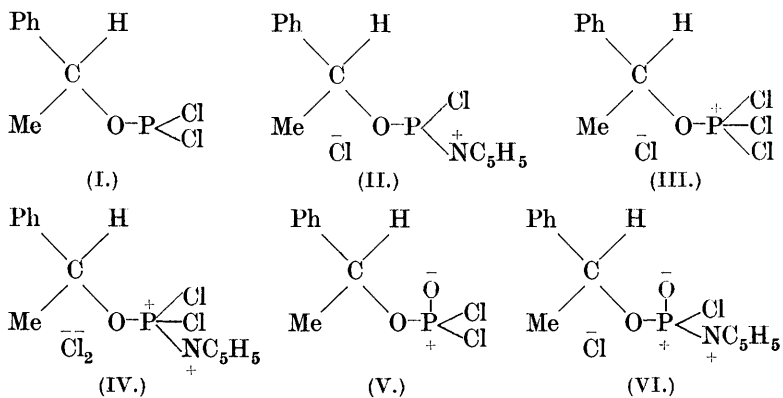
*The Specific Rotatory Powers of  $\alpha$ -Chloroethylbenzene obtained by the Halogenation of 1-Phenylmethylcarbinol.\**

Halogenating agent.	Tertiary base.	Specific rotatory power of <i>l</i> -alcohol, $[\alpha]_{5461}$	Specific rotatory power of $\alpha$ -chloroethylbenzene, $[\alpha]_{5461}$ .	Observer.
SOCl <sub>2</sub> , 2.5 mols.	None	-51.7°	-63.3°	McK and C.
SOCl <sub>2</sub> , 2.0 mols.	Pyridine, 1 mol.	49.8	+17.3	K, P and T.
SOCl <sub>2</sub> , 2.0 mols.	Pyridine, 2 mols.	49.8	+36.3	K, P and T.
SOCl <sub>2</sub> , 2.0 mols.	Quinoline, 2 mols.	43.7	+16.1	K, P and T.
HCl	None	51.0	+6.9	P and K.
PCl <sub>3</sub> , 3.5 mols.	None	51.7	+10.1	McKand C.
PCl <sub>3</sub> , 2.0 mols.	K <sub>2</sub> CO <sub>3</sub>	51.7	+10.0	K, P and T.
PCl <sub>3</sub> , 2.0 mols.	Pyridine, 1 mol.	49.8	+64.1	K, P and T.
POCl <sub>3</sub> , 2.5 mols.	None	28.0	+0.5	K, P and T.
POCl <sub>3</sub> , 2.0 mols.	Pyridine, 1 mol.	52.1	+12.6	K, P and T.
PCl <sub>5</sub> , 2.0 mols.	None	43.7	+4.5	K, P and T.
PCl <sub>5</sub> , 2.0 mols.	Pyridine, 1 mol.	49.8	+10.4	K, P and T.

\* Throughout the theoretical portion of this paper it is assumed that only *l*-phenylmethylcarbinol was used. Actually, some of these experiments were performed with the *d*-alcohol.

It can be seen from Table I that, as in the previous experiments with ethyl *l*-mandelate, the presence of either pyridine or quinoline causes a reversal in the sign of rotation of the  $\alpha$ -chloroethylbenzene obtained when thionyl chloride is used. When, however, the chlorides or oxychloride of phosphorus are used in the presence of pyridine, the signs of rotation of the  $\alpha$ -chloroethylbenzenes obtained are the same as in its absence but the magnitudes of the rotations are greater. In other words, pyridine facilitates the occurrence of the reactions which lead to change of sign of rotation, which, according to Kenyon, Lipscomb, and Phillips (*loc. cit.*), is indicative of a change of configuration.

The explanation advanced to account for the influence of pyridine on the mode of interaction of ethyl *l*-mandelate and thionyl chloride (*loc. cit.*) is applicable to the present results obtained with phenylmethylcarbinol and can be extended to account for the influence of pyridine on the mode of interaction of this alcohol with the chlorides and oxychloride of phosphorus.



As depicted above, the intermediate phases in these reactions, (II), (IV), and (VI), have two features in common with the intermediate phases which arise in other Walden inversion reactions which have been studied (Houssa, Kenyon, and Phillips, *J.*, 1929, 1700). These two important features are that the group about to leave the molecule has been rendered predominantly positive in character, whilst the entering group (the chlorine atom) exists as an anion and can therefore take up a favourable position in the complex to ensure inversion (Kenyon and Phillips, *Trans. Faraday Soc.*, 1930, **26**, 451). The tertiary base facilitates the occurrence of an inversion for two reasons. It displaces as a chlorine ion, a chlorine atom covalently linked to the phosphorus atom and by reason of the linkage which it thus forms with the phosphorus atom creates an additional positive centre in the group about to leave the molecule. The creation of this additional positive centre weakens the linkage between the asymmetric carbon atom and the group, and also enables this group, when it departs, to abstract the bonding electrons from the octet of the asymmetric carbon atom. This carbon atom is thus left positively charged and in a condition in which it can combine with a negative ion in a manner likely to lead to an inversion.

When used in conjunction with pyridine, the chlorides and oxychloride of phosphorus give a greater yield of the desired chloride. This result is in agreement with the greater yield of methyl *dl*-

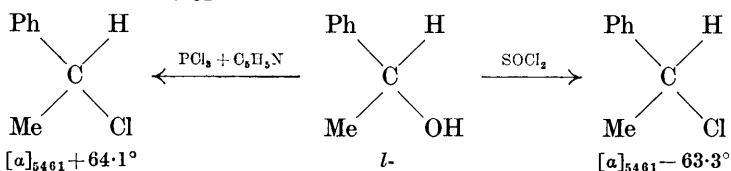
phenylchloroacetate obtained by the combined action of phosphorus oxychloride and pyridine on methyl *dl*-mandelate (Wagner-Jauregg, *Helv. Chim. Acta*, 1928, **12**, 61) and with the observation of Boyd and Ladhams (J., 1928, 215) that the diaryloxyisopropyl chlorides are not formed from the corresponding alcohols in the presence of phosphorus oxychloride alone, but only when pyridine is present.

The presence of potassium carbonate was without influence on the magnitude of the rotatory power of the  $\alpha$ -chloroethylbenzene obtained by the interaction of the *l*-alcohol with phosphorus trichloride. It is probable, therefore, that the hydrogen chloride produced in the initial stage of this interaction plays no further part in the reaction, and that the  $\alpha$ -chloroethylbenzene produced arises through the decomposition of the intermediate compound (I). According to Kenyon and Phillips (*loc. cit.*), it is necessary that a chlorine anion should be the first product of the decomposition of such intermediate compounds in order that an optically active chloride may result with inversion of configuration. If, however, the phenylmethylcarbiny radical separates as a kation before this chlorine anion becomes free, racemisation will occur as in the transformation of *d*-phenylmethylcarbiny *p*-toluenesulphinate into *dl-p*-tolyl- $\alpha$ -phenylethylsulphone (Kenyon and Phillips, J., 1930, 1676). Alternatively, the phenylmethylcarbiny radical may initiate the decomposition by separating as an anion, in which case an optically active chloride of the same configuration as the alcohol will be produced. In the absence of pyridine, which causes the inversion reaction to predominate, the decomposition of the intermediate compound of the interaction of phosphorus trichloride and the alcohol (I) appears to follow an indefinite course in which all the methods of decomposition enumerated above may occur, since *d*- $\alpha$ -chloroethylbenzene with  $[\alpha]_{5461} + 10.1^\circ$  is obtained in place of the probably optically pure chloride with  $[\alpha]_{5461} + 64.1^\circ$  which is obtained when the decomposition occurs in the presence of pyridine.

It would appear that, in the absence of pyridine, the decomposition of the intermediate compound of the interaction of the oxychloride and the alcohol (V) is initiated by the separation of a phenylmethylcarbonium kation without the simultaneous production of a chlorine anion. On this assumption, it is possible to account for the observed formation of styrene and its polymerides, optically active  $\alpha\alpha$ -diphenyldiethyl ether, and an almost optically inactive  $\alpha$ -chloroethylbenzene.

The result of the combined action of pyridine and phosphorus trichloride on *l*-phenylmethylcarbinol is noteworthy. McKenzie and Clough (*loc. cit.*) found that, when the reaction between the

*l*-alcohol and thionyl chloride was carefully controlled, the *l*- $\alpha$ -chloroethylbenzene obtained always possessed a specific rotatory power of about  $[\alpha]_{5893} - 51^\circ$  ( $[\alpha]_{5461} - 63^\circ$ ). This constancy in the magnitude of the rotatory power of the product was advanced as a reason for concluding that the reaction occurred without any appreciable racemisation. It is therefore significant that, in the presence of pyridine, phosphorus trichloride gave *d*- $\alpha$ -chloroethylbenzene with  $[\alpha]_{5461} + 64^\circ$ .



Kenyon, Lipscomb, and Phillips (*loc. cit.*) have suggested that the interaction of thionyl chloride with hydroxyl compounds containing a phenyl group directly attached to the asymmetric carbon atom is not attended with inversion. If the reaction between thionyl chloride and *l*-phenylmethylcarbinol is also unattended by racemisation, it follows that the interaction of phosphorus trichloride and the *l*-alcohol, in the presence of pyridine, occurs with complete inversion of configuration.

#### EXPERIMENTAL.

The optically active phenylmethylcarbinol required was prepared by the procedure of Houssa and Kenyon (J., 1930, 2260).

*dl*- $\alpha$ -Chloroethylbenzene was prepared by the action of thionyl chloride on the *dl*-alcohol (McKenzie and Clough, *loc. cit.*) (Found: Cl, 25.2. Calc.: Cl, 25.2%). *dl*- $\alpha$ -Chloroethylbenzene has  $n_D^{20} 1.5280$ ,  $n_D^{25} 1.5269$ ,  $n_D^{30} 1.5264$ ,  $n_D^{35} 1.5253$ , and  $n_D^{40} 1.5230$ . The purity of the products obtained in the experiments described below was judged by comparison of their refractive indices with these values.

*Interaction of Optically Active Phenylmethylcarbinol with Halogenating Agents.*—(i) *With thionyl chloride.* (a) *Using one molecular proportion of pyridine.* Thionyl chloride (4.76 g.; 2 mols.) was added slowly to an agitated solution of the *l*-alcohol [2.44 g.; 1 mol.;  $\alpha_{5461} - 12.6^\circ$  ( $l = 0.25$ )] in pyridine (1.58 g.; 1 mol.), cooled in ice and salt. The resulting mixture was warmed at  $50^\circ$  for about 30 minutes and then poured into water, from which the  $\alpha$ -chloroethylbenzene was extracted with methylene chloride. The methylene chloride extract was washed successively with dilute hydrochloric acid, dilute aqueous sodium carbonate, and water, and dried over potassium carbonate. The *d*- $\alpha$ -chloroethylbenzene (2.3 g.), b. p.  $78^\circ/18$  mm., obtained after evaporation of the solvent,

was repeatedly fractionally distilled until it had  $n_D^{26}$  1.5252. It then had  $\alpha_{5461} + 4.7^\circ$  ( $l = 0.25$ ).

(b) *Using two molecular proportions of pyridine.* The reaction was carried out as described above except that 3.16 g. of pyridine were used. The *d*- $\alpha$ -chloroethylbenzene (1.3 g.) obtained had  $n_D^{26}$  1.5272 and  $\alpha_{5461} + 9.68^\circ$  ( $l = 0.25$ ).

(c) *Using three molecular proportions of pyridine.* Very small yields of  $\alpha$ -chloroethylbenzene were obtained, probably owing to the combination of the  $\alpha$ -chloroethylbenzene produced with the excess of pyridine.

(d) *Using two molecular proportions of quinoline.* The *d*-alcohol [2.44 g.;  $\alpha_{5461} + 44.28^\circ$  ( $l = 1.0$ )], thionyl chloride (4.76 g.; 2 mols.), and quinoline (5.16 g.; 2 mols.) were employed and the reaction was carried out as described in (a) above. The *l*- $\alpha$ -chloroethylbenzene (2.0 g.), b. p.  $81^\circ/21$  mm., had  $\alpha_{5461} - 4.3^\circ$  ( $l = 0.25$ ).

(ii) *With phosphorus trichloride.* (a) *In the presence of pyridine.* A solution of the *l*-alcohol [2.44 g.; 1 mol.;  $\alpha_{5461} - 12.6^\circ$  ( $l = 0.25$ )] in pyridine (1.58 g.; 1 mol.) was added slowly to phosphorus trichloride (5.5 g.; 2 mols.) cooled in an ice-salt mixture. The reactants were well shaken between each addition of the alcohol, and after warming at  $50^\circ$  for about 30 minutes the  $\alpha$ -chloroethylbenzene was extracted and purified as described above. The final product (2.0 g.), b. p.  $81^\circ/21$  mm., had  $n_D^{26}$  1.5280 and  $\alpha_{5461} + 17.3^\circ$  ( $l = 0.25$ ).

(b) *In the presence of potassium carbonate.* The *l*-alcohol [2.44 g.;  $\alpha_{5461} - 13.1^\circ$  ( $l = 0.25$ )] in ether (10 c.c.) was added slowly and with constant shaking to an ice-cold mixture of phosphorus trichloride (5.5 g.; 2 mols.) and anhydrous potassium carbonate (5.5 g.; 2 mols.) in ether (10 c.c.). The excess of phosphorus trichloride and the ether were removed under diminished pressure and the product was extracted by means of ether from the dry residue obtained. From this ethereal extract *d*- $\alpha$ -chloroethylbenzene (0.5 g.), b. p.  $86^\circ/25$  mm., with  $\alpha_{5461} + 2.5^\circ$  ( $l = 0.25$ ) was obtained together with a high-boiling residue which was optically inactive.

(iii) *With phosphorus oxychloride.* (a) *In the presence of pyridine.* The *d*-alcohol [2.44 g.; 1 mol.;  $\alpha_{5461} + 6.52^\circ$  ( $l = 0.25$ )], dissolved in pyridine (1.58 g.; 1 mol.), was added with constant agitation to phosphorus oxychloride (6.2 g.; 2 mols.). After extraction in the usual manner,  $\alpha$ -chloroethylbenzene (1.9 g.), b. p.  $86^\circ/25$  mm.,  $n_D^{18}$  1.5312,  $\alpha_{5461} - 2.58^\circ$  ( $l = 0.25$ ), was obtained. In a further experiment using the *l*-alcohol [2.44 g.;  $\alpha_{5461} - 13.23^\circ$  ( $l = 0.25$ )]  $\alpha$ -chloroethylbenzene (2.0 g.), b. p.  $86^\circ/25$  mm.,  $n_D^{25}$  1.5259,  $\alpha_{5461} + 3.21^\circ$  ( $l = 0.25$ ), was obtained.

(b) *In the absence of pyridine.* (a) *At 40—50° in ether or carbon tetrachloride, phosphorus oxychloride (2 mols.) being used.* In these

experiments the phenylmethylcarbinol (9.6 c.c.; 1 mol.) was added to the phosphorus oxychloride in 100 c.c. of solvent. It was found that if, after 30 minutes, the solvent was removed a tarry undistillable mass was obtained. If, after 30—45 minutes, the reaction mixture was washed with water, dried, and distilled, only traces of the alcohol and  $\alpha$ -chloroethylbenzene were obtained, the main product being styrene and a polymeride of styrene, b. p.  $160^{\circ}/1$  mm. (Found: C, 92.0; H, 7.6. Calc.: C, 92.3; H, 7.7%).

( $\beta$ ) At  $20^{\circ}$  in ether, phosphorus oxychloride (2—3 mols.) being used. In these experiments the phenylmethylcarbinol (9.6 c.c.; 1 mol.) was added to the phosphorus oxychloride (2—3 mols.) in ether (100 c.c.). After periods of time ranging from 24—48 hours, the reaction mixtures were washed with water, dried, and distilled. The products were practically free from styrene and its polymerides and consisted of  $\alpha$ -chloroethylbenzene and  $\alpha\alpha$ -diphenyldiethyl ether, b. p.  $159$ — $160^{\circ}/18$  mm.,  $n_D^{17}$  1.5454 (Found: C, 84.6; H, 7.8. Calc.: C, 85.0; H, 7.9%).

When *d*-phenylmethylcarbinol [ $\alpha_{5461} + 7.10^{\circ}$  ( $l = 0.25$ )] was used, the  $\alpha$ -chloroethylbenzene isolated had  $n_D^{25}$  1.5295 and  $\alpha_{5461} - 0.15^{\circ}$  ( $l = 0.25$ ), whilst the  $\alpha\alpha$ -diphenyldiethyl ether had  $n_D^{21}$  1.5454, and  $\alpha_{5461} + 20.30^{\circ}$  ( $l = 0.25$ ).

(iv) With phosphorus pentachloride. (a) In the absence of pyridine. McKenzie and Clough (*loc. cit.*) were unable to isolate any definite product from the direct action of phosphorus pentachloride on phenylmethylcarbinol. The methods outlined below gave  $\alpha$ -chloroethylbenzene in 70% yield. ( $\alpha$ ) The *d*-alcohol [2.44 g.;  $\alpha_{5461} + 44.28^{\circ}$  ( $l = 1.0$ )] was added to ice-cold phosphorus pentachloride (8.5 g.; 2 mols.). At the end of the initial vigorous reaction, the mixture was warmed on a steam-bath and then kept at the ordinary temperature for 30 minutes. The product was dissolved in methylene chloride and the solution obtained was washed with water and dried. From this solution *l*- $\alpha$ -chloroethylbenzene (1.5 g.) was obtained, b. p.  $81^{\circ}/21$  mm.  $n_D^{20}$  1.5293, and  $\alpha_{5461} - 1.21^{\circ}$  ( $l = 0.25$ ).

( $\beta$ ) The *dl*-alcohol (4.88 g.; 1 mol.), dissolved in dry ether (15 c.c.), was added to a solution of phosphorus pentachloride (2 mols.) in boiling ether (50 c.c.). The ethereal solution was heated under reflux for 15 minutes, washed successively with water and dilute sodium carbonate solution, and dried with potassium carbonate. After evaporation of the ether,  $\alpha$ -chloroethylbenzene (4.9 g.) was obtained, b. p.  $86^{\circ}/27$  mm.,  $n_D^{21.9}$  1.5284.

(b) In the presence of pyridine. A solution of the *l*-alcohol [2.44 g.; 1 mol.;  $\alpha_{5461} - 12.6^{\circ}$  ( $l = 0.25$ )] in pyridine (1.58 g.; 1 mol.) was added to the phosphorus pentachloride (8.5 g.; 2 mols.)

cooled in an ice-salt mixture. After warming at  $50^{\circ}$  for 30 minutes, the  $\alpha$ -chloroethylbenzene (2.0 g.) was extracted in the usual manner : b. p.  $78^{\circ}/19$  mm.,  $n_D^{21.8}$  1.5258,  $\alpha_{5461} + 2.78^{\circ}$  ( $l = 0.25$ ).

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