71. *The Elimination of Carbon Monoxide from Acid Derivatives. Part I. Kinetic Measurements with Some Diarylacetyl Chlorides.*

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The Friedel–Crafts rates of elimination of carbon monoxide and of the overall reactions have been measured for some *para*-substituted diphenylacetyl chlorides. Electron-releasing groups accelerate the elimination reactions, whilst the opposite is true when electrons are withdrawn from the seat of reaction. Ketone formation is affected in a similar way but to a much smaller extent.

THE Friedel–Crafts elimination of carbon monoxide from diphenyl- and phenyl-*p*-tolylacetyl chloride recorded by Rothstein and Saville [1] affords an opportunity for examining polar influences on this reaction in examples where little or no steric interaction is to be expected. The greater accessibility of secondary than of tertiary acids largely compensates for the occurrence of a somewhat more complex reaction, including ketone formation, whilst the slower evolution of carbon monoxide facilitates its measurement. In these experiments deactivation of the catalyst by the ketone formed was, in most cases, minimised by making the catalyst : acid chloride ratio 5 : 1. This deactivation was then hardly noticeable but even when the ratios were very much smaller the reaction constants obtained were not fundamentally affected. The reaction order with respect to the catalyst varied between 1·4 and 1·7, but the difference from the value of 2 was not unexpected since as was suggested by Grundy, Hsü, and Rothstein [2] acid chlorides may form complexes with both monomeric and dimeric aluminium chloride present in the equilibrium mixture, $2AlCl_3 \rightleftharpoons Al_2Cl_6$.

It can be recalled that three types of complex formation were envisaged, these leading, with reference to the catalyst, to first- or second-order kinetics:

$$Ar_2CH{\cdot}COCl + AlCl_3 \longrightarrow Ar_2CH{\cdot}CO^+AlCl_4^- \quad \text{First order}$$
$$Ar_2CH{\cdot}COCl + Al_2Cl_6 \longrightarrow Ar_2CH{\cdot}CO^+AlCl_4^- + AlCl_3 \quad \text{Second order}$$
$$Ar_2CH{\cdot}COCl + Al_2Cl_6 \longrightarrow Ar_2CH{\cdot}CO^+Al_2Cl_7^- \quad \text{Second order}$$

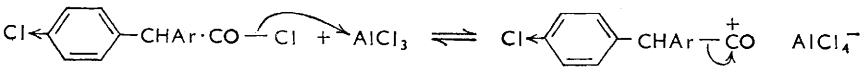
Further reaction results in either elimination of carbon monoxide or formation of ketone:

$$Ar_2CH{\cdot}CO^+ \xrightarrow{} CO + Ar_2CH^+$$
$$Ar_2CH{\cdot}CO^+ \xrightarrow[Ar'H]{} Ar_2CH{\cdot}COAr'$$

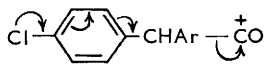
The first reaction is kinetically of the first order with respect to the acid chloride; the second, in general, is also of the first order as regards the acid chloride but as it involves the aromatic component it is of the second order overall. However, since the Ar'H is usually the solvent, first-order kinetics are observed. For the faster reactions it appears probable that there is not an appreciable concentration of complex at any stage, *i.e.*, the final stage of the reaction is faster than any intermediate stage. For instance, elimination of carbon monoxide from diarylacetyl chlorides has not been observed in anisole solution; on the other hand phenyl-*p*-tolylacetyl chloride in benzene yields only carbon monoxide, and no ketone. If k is the overall rate, and k' and k'' are the rates of carbon monoxide elimination and ketone formation respectively, it is evident that the observed rate constant for the former reaction is $k'k/(k' + k'')$ and consequently is equal to k only when k'' is very small. On the other hand, if the rate of removal of complex is less than that of its formation, so that its concentration is virtually constant, the observed rate constant for the elimination reaction is equal to k'. It follows that, because a change in the rate of elimination of carbon monoxide may be accompanied by a stationary, increased, or

[1] Rothstein and Saville, *J.*, 1949, 1961.
[2] Grundy, Hsü, and Rothstein, *J.*, 1956, 4561.

decreased rate of ketone formation, additional data are necessary before the effect of groups can be properly discussed. This can be exemplified by considering the effect of halogen in the *para*-position:



Here the inductive effect of chlorine tends to retard complex formation and, even more so, liberation of carbon monoxide since there is one less intervening carbon atom to damp electronic displacements. Electrophilic ketone formation would, however, be favoured and in this case the overall reaction be less retarded than the measured elimination of carbon monoxide. The contrary is true of a positive inductive ($+I$) effect, where acceleration of complex formation should lead to slight retardation of ketone formation and to a relatively greater rate of elimination. A positive tautomeric ($+T$) effect arising from hyperconjugation for a *p*-methyl substituent or from an increase in covalency in the case of halogen (cf. A) facilitates release of carbon monoxide but, if the small permanent ($+M$) component is ignored (its effect must in any case be relayed through a saturated chain), this ($+T$) effect can have no influence on the formation of either complex or ketone. The exclusive production of carbon monoxide from phenyl-*p*-tolylacetyl chloride and the difference in reaction rates between the *p*-chloro- and *p*-bromo-acid chloride (see below) afford some indication of these T effects.



(A)

A summary of the experimental results is given in Tables 1 and 2. A method for estimating the rate of ketone formation has not yet been developed; instead, the reactions have, in certain cases, been carried out on a preparative scale under approximately the same conditions as the kinetic runs, the ketones being then isolated. Since both reactions are of the same kinetic order, the yields afford a rough measure of the relative rate of ketone formation. The total reaction rate was measured by titrating the acid obtained by hydrolysis of unchanged acid chloride.[3] Exigencies of the method necessitated an excess of acid chloride and a low concentration of catalyst, conditions which were entirely different from those of the experiments of Table 1.

TABLE 1. *Reaction constants for the elimination of carbon monoxide from diarylacetyl chlorides, including the yields of carbon monoxide and ketone.* [ArAr'CH·COCl] = 0·05 mole/l. Temp. 20·36°.

Ar	Ar'	[$AlCl_3$] (mole/l.)	10^2k_1 (min.$^{-1}$)	Yields (%) CO	Ketone
Ph	*p*-Tolyl	0·25	5·25	87·5	0
,,	,,	0·05	0·32	48·0	0
,,	Ph	0·25	0·601	48·0	38 *
p-Cl·C_6H_4	*p*-Tolyl	0·25	0·543	49·5	10—20
,,	,,	0·05	0·055	15·0	—
,,	Ph	0·25	0·117	18·0	62
p-Br·C_6H_4	,,	0·25	0·093	14·5	—

* Rothstein and Saville [1] carried out this reaction in carbon disulphide in the presence of a small excess of benzene. The total yield of carbon monoxide was 68% and that of ketone 30%.

The values in Table 2 are of limited accuracy as only one determination in each case could be carried out. On the whole, however, the figures are well separated and a number of inferences may be made. The value for diphenylacetyl chloride is not available but would presumably lie near that of *p*-chlorophenyl-*p*-tolylacetyl chloride.

When the proper allowance is made for the different catalyst concentration it appears from the Tables that the value of the reaction constant for the elimination of carbon monoxide from phenyl-*p*-tolylacetyl chloride is the same as that for the overall reaction,

[3] Rothstein and Saville, *J.*, 1949, 1954.

showing the absence of ketone formation and the unimportance of relative concentrations of acid chloride and catalyst. It is the only example (Table 2) where the molecular

TABLE 2. *Overall reaction rates of diarylacetyl chlorides with benzene.* [ArAr'CH·COCl] = 0·1 mole/l. Temp. 20·0°.

Ar	Ar'	[$AlCl_3$] (mole/l.)	Reaction measured (%)	10^2k_1 (min.$^{-1}$)
Ph	*p*-Tolyl	0·063	72	0·462
p-Cl·C_6H_4	*p*-Tolyl	0·063	43	0·125
,,	Ph	0·063	25	0·0340
p-Br·C_6H_4	,,	0·063	27	0·0347
,,	,,	0·126	45	0·184

proportion of the acid derivative transformed is greater than that of the catalyst. Further, the deactivating effect of halogen is much greater on the elimination reaction (Table 1) than it is on the overall reaction (Table 2), that is, ketone formation is the result of a disproportionate decrease in the carbon monoxide evolved. This suggests that the reaction between the acid chloride and aluminium chloride is no longer rate-determining so far as elimination is concerned. The marked increase in the rate of elimination when chlorine is substituted for bromine without a corresponding increase in the overall rate indicates that this may be the case, the increase itself being a consequence of the greater $+T$ effect of chlorine than of bromine.

In so far as ketone formation is the slow stage of the reaction, the foregoing may be compared with Olivier's kinetic determinations for the reaction of *para*-substituted benzenesulphonyl chlorides with benzene.[4] In these experiments the rate of sulphone formation was directly proportional to the concentration of aluminium chloride so long as this was equal to, or less than, that of the sulphonyl chloride. Excess of the catalyst was approximately 200 times as effective as the " combined " material,[5] a discontinuity not observable in our reactions. In the former case, with 0·1 mole/l. of catalyst and sulphonyl chloride, the following figures are comparable with those of Table 2, even in the relative order of the chloro- and bromo-substituted compounds:

R in *p*-R·C_6H_4·SO_2Cl	Me	H	Br	Cl
10^2k_1	0·646	0·212	0·110	0·106

EXPERIMENTAL

Preparation of Diarylacetic Acids.—Mandelic acid or the appropriately *para*-substituted derivative was condensed with benzene or *para*-substituted benzene in the presence of anhydrous stannic chloride.[6] Thus phenyl-*p*-tolylacetic acid was prepared, first, from mandelic acid and toluene, and, secondly, from *p*-methylmandelic acid and benzene; similarly both *p*-chlorophenyl-phenylacetic acid and *p*-chlorophenyl-*p*-tolylacetic acid were each obtained in two ways. This confirmed that the substituent groups were in the *para*-positions. The mandelic acids were synthesised from the aldehyde by conversion into the cyanohydrin followed by hydrolysis.[7] Thus *p*-tolualdehyde furnished *p*-methylmandelic acid, m. p. 145° in 80% yield (Found: C, 65·2; H, 6·1. Calc. for $C_9H_{10}O_3$: C, 65·0; H, 6·0%), and this in turn condensed with benzene to yield phenyl-*p*-tolylacetic acid, m. p. 116°, identical (m. p. and mixed m. p.) with the acid previously prepared by the original method [6] [acid chloride, b. p. 136°/1 mm. (Found: C, 73·4; H, 5·6; Cl, 14·5. Calc. for $C_{15}H_{13}OCl$: C, 73·6; H, 5·4; Cl, 14·5%)].

In the following preparations it was usually advantageous to convert the crude diarylacetic acid, often obtained in a non-crystallisable form, into the methyl or ethyl ester by saturating a solution in a slight excess of alcohol with dry hydrogen chloride. After fractionation the pure ester was nearly quantitatively hydrolysed by alcoholic potassium hydroxide.

[4] Olivier, *Rec. Trav. chim.*, 1914, **33**, 245.
[5] *Idem, ibid.*, 1915, **35**, 109.
[6] McKenzie and Widdows, *J.*, 1915, **107**, 702.
[7] Jenkins, *J. Amer. Chem. Soc.*, 1931, **53**, 2341.

The resulting acid was pure but could be recrystallised from acetic acid or from methanol. Condensation either of mandelic acid with chlorobenzene,[8] or of *p*-chloromandelic acid with benzene, afforded *p*-chlorophenyl-phenylacetic acid, m. p. 115·5° (Found: C, 68·2; H, 4·7; Cl, 14·2. Calc. for $C_{14}H_{11}O_2Cl$: C, 68·2; H, 4·5; Cl, 14·7%). This gave an *ethyl ester*, b. p. 135°/0·07 mm. (Found: C, 70·1; H, 5·6. $C_{16}H_{15}O_2Cl$ requires C, 70·0; H, 5·6%), and an *acid chloride*, b. p. 153°/1·5 mm., 145°/0·1 mm. (Found: C, 64·1; H, 3·8; Cl, 26·9. $C_{14}H_{10}OCl_2$ requires C, 63·4; H, 3·8; Cl, 26·8%).

Similarly, mandelic acid and bromobenzene yielded a non-crystallisable oil from which was obtained *methyl* p-*bromophenylphenylacetate*, b. p. 145°/0·1 mm. (Found: C, 59·3; H, 4·3; Br, 26·2. $C_{15}H_{13}O_2Br$ requires C, 59·0; H, 4·3; Br, 26·2%). Hydrolysis furnished p-*bromophenylphenylacetic acid*, separating from dilute methanol in needles, m. p. 120—121° (Found: C, 57·7; H, 3·8; Br, 27·7. $C_{14}H_{11}O_2Br$ requires C, 57·7; H, 3·8; Br, 27·4%). The acid *chloride*, b. p. 149°/0·5 mm., probably contained a trace of acid (Found: C, 55·3; H, 3·4; Cl + Br, 36·8. $C_{14}H_{10}OClBr$ requires C, 55·3; H, 3·2; Cl + Br, 37·3%).

p-*Chlorophenyl*-p-*tolylacetic acid*, m. p. 144—145°, was obtained by condensing either *p*-chloromethylmandelic acid with toluene, or *p*-methylmandelic acid with chlorobenzene (Found: C, 69·4; H, 4·9; Cl, 13·7. $C_{15}H_{13}O_2Cl$ requires C, 69·1; H, 5·0; Cl, 13·6%), and gave a *methyl ester*, b. p. 146—147°/0·1 mm. (Found: C, 70·3; H, 5·6. $C_{16}H_{15}O_2Cl$ requires C, 70·0; H, 5·5%), and an acid chloride, b. p. 157°/1·3 mm., 135—140°/0·1 mm.

Qualitative Friedel–Crafts Condensations.—The concentrations of the reagents were those used for the kinetic measurements, *i.e.*, $AlCl_3$ 0·25 mole/l., acid chloride 0·5 mole/l. The composition of the solvent was benzene 890 c.c./l., and nitrobenzene 110 c.c./l. The reagents were stirred together at room temperature for about 18 hr.

(i) Diphenylacetyl chloride yielded diphenylacetophenone (38%).

(ii) Chlorophenylphenylacetyl chloride gave a small quantity of an oil, b. p. 140—160°/0·08 mm. The main product was *chlorophenylphenylacetophenone* (crude yield, 62%). It separated from methanol in needles, m. p. 106—107° (Found: C, 78·1; H, 5·1; O, 5·2. $C_{20}H_{15}OCl$ requires C, 78·3; H, 4·9; O, 5·2%).

(iii) p-*Chlorophenyl*-p-*tolylacetophenone*, b. p. 176°/0·11 mm., resulted from the reaction with *p*-chlorophenyl-*p*-tolylacetyl chloride and crystallised. Recrystallisation from methanol afforded needles, m. p. 95—96° (total yield, including the small amount mentioned below, 10—20%) (Found: C, 79·0; H, 4·5; Cl, 11·3. $C_{21}H_{17}OCl$ requires C, 78·6; H, 5·3; Cl, 11·8%). The bulk of the product of the reaction was an oil, b. p. 167°/0·11 mm., which showed some ketonic absorption at 1698 cm.$^{-1}$. A cold solution in ligroin (b. p. 40—60°) slowly deposited brown crystals. Filtration and fractionation yielded an oil, b. p. 155—158°/0·08 mm., which showed very low absorption at 1698 cm.$^{-1}$. Analysis suggested that it might be p-*chlorophenyl-phenyl*-p-*tolylmethane* (Found: C, 82·0; H, 6·1; Cl, 11·8. $C_{20}H_{17}Cl$ requires C, 82·1; H, 5·8; Cl, 12·1%). Very little infrared absorption characteristic of methyl was observed but this was found to be the case with other nuclear methyl groups though not for methyl in the side chain (Table 3). C–H stretching frequencies in the infrared spectrum occur at approximately 1955 and 1865 cm.$^{-1}$, but only in the case of 1 : 1-diphenylethane are both absorptions prominent.

TABLE 3. *Principal infrared bands (cm.$^{-1}$) in the 3 μ region of some diarylalkanes (thin films) (italicised figures refer to methyl absorptions).*

Ph_2CH_2	Ph_2CHMe	*p*-$C_6H_4Me{\cdot}CH_2Ph$	*p*-$Cl{\cdot}C_6H_4{\cdot}CH_2{\cdot}C_6H_4Me$-*p*	
3080	3077	3080	3085	Aromatic C–H
3058	3053	—	3059	
3022	3032	3020	3028	
—	*2964*	—	—	
2906	2927	2916	2927	
—	*2870*	—	*2872*	
2838	—	—	—	

Kinetic Measurements.—Table 4 includes details of measurements for one example of each acid chloride examined by the carbon monoxide method. Table 5 similarly gives the results obtained by the titration method. Only one run was carried out by this method for each acid chloride. The complete set of reaction constants has already been given in Tables 1 and 2.

[8] Ettel, Semonsky, and Zikan, *Chem. Listy*, 1952, **46**, 499.

TABLE 4. *Carbon monoxide evolved from diarylacetyl chlorides.*

[ArAr'CH·COCl] = 0·05 mole/l. [$AlCl_3$] = 0·25 mole/l. Temp. 20·36°.

CO (mole/l.) Ar = Ph, Ar' = *p*-Tolyl		CO (mole/l.)				
			Ph Ph	*p*-Cl·C_6H_4 *p*-Tolyl	*p*-Cl·C_6H_4 Ph	*p*-Br·C_6H_4 Ph
Time (min.)	No. 74	Time (min.)	No. 72	No. 83	No. 78	No. 82
6	0·00677	15	0·00463	0·00512	0·00060	0·000478
12	0·01897	30	0·00942	0·01000	0·00159	0·001260
18	0·02745	45	0·01310	0·01371	0·00252	0·002034
24	0·03284	60	0·01573	0·01641	0·00333	0·002743
30	0·03647	75	0·01780	0·01849	0·00406	0·003378
45	0·04150	90	0·01944	0·02010	0·00471	0·003941
60	0·04335	105	0·02068	0·02138	0·00530	0·004444
75	0·04405	120	0·02172	0·02240	0·00583	0·004896
—	—	135	0·02258	0·02319	0·00632	0·005319
—	—	150	0·02332	0·02382	0·00677	0·005671
—	—	165	0·02392	0·02432	0·00717	0·006002
—	—	180	0·02445	0·02472	0·00754	0·006300
—	—	240	—	—	0·00868	0·007270
10^3k_1 (min.$^{-1}$)	5·37 (55)		0·668 (26)	0·543 (37)	0·113 (9)	0·865 (9)

Figures in parentheses refer to percentage of reaction used for calculating the reaction constant.

TABLE 5. *Titration method: progress of reactions of* (*A*) *phenyl*-p-*tolyl*-, (*B*) p-*chlorophenyl*-p-*tolyl*-, (*C*) p-*chlorophenylphenyl*-, *and* (*D*) p-*bromophenylphenyl-acetyl chlorides. Temp.* 20·0°.

[ArAr'CH·COCl] = 0·10 mole/l. [$AlCl_3$] = 0·063 mole/l.

(*A*)	Time (min.) ...	3	10	25	55	115	236	360
	Reaction (%) ...	9·5	10·0	16·2	31·4	42·8	61·9	71·8
(*B*)	Time (min.) ...	3·5	15	55	161	290	410	1041
	Reaction (%) ...	12·0	14·5	20·2	26·4	31·2	32·0	42·7
(*C*)	Time (min.) ...	5	16	47	108	243	365	607
	Reaction (%) ...	7·7	8·6	10·3	12·6	17·1	19·3	25·3
(*D*)	Time (min.) ...	4·2	25	76	165	319	447	648
	Reaction (%) ...	7·7	9·6	10·4	13·3	17·7	20·5	22·7

The analyses were carried out in the Microanalytical Department of the School of Chemistry.

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