CXVIII.—*The Preparation of Mixed Ketones by Heating the Mixed Calcium Salts of Organic Acids.*

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The method of heating a calcium salt in a sulphur vapour bath so as to form the corresponding ketone and of removing the ketone, as soon as formed, by a current of carbon dioxide (Young, Trans., 1891, **59**, 623) gave such remarkably good results in the case of dibenzyl ketone that it seemed desirable to test its general applicability, and, in particular, to extend the method to the case of mixtures of calcium salts.

As the yield of crude ketone was 93 per cent. in the simple case where the calcium salt of only one acid was heated, and the whole preparation was effected with ease, it appeared probable that interesting information would be obtained as to the course of the decomposition if the simple salt were replaced by mixtures. Had the yield of unmixed ketone not been so good, it would have made it very difficult to draw any conclusions of value when dealing with mixtures, for, in addition to the slight loss in the formation of the ketones, there is the increased difficulty of separating them from one another and obtaining them pure.

On subjecting a mixture of two calcium salts to the action of heat, three ketones are formed and collect together in the distillate. It is possible by collecting the distillate in fractions to effect a preliminary separation, which, however, is only slight, as the ketones are formed simultaneously, distilling and condensing together. This fact made it important to select such ketones as could easily be separated by a subsequent fractional distillation, and this was also convenient for another reason, namely, that in connection with another investigation a ketone was required in which the two groups attached to the carbon atom of the carbonyl group should be markedly different.

The acids first employed were acetic and phenylacetic. On heating mixtures of the calcium salts of these two acids, dimethyl, methyl

benzyl, and dibenzyl ketones are obtained, and as they boil respectively at 56°, 217°, and 330°, there is no difficulty in separating them by fractional distillation. Moreover, the mixed ketone contains the two radicles methyl and benzyl, which were sufficiently unlike to render the ketone a suitable one for further investigation.

Subsequently calcium phenylacetate was distilled with calcium propionate and with calcium butyrate respectively. The fractionation of the ketones obtained from these salts was again quite an easy operation.

Preparation of Methyl Benzyl Ketone.

The preparation was carried out with various proportions of the two salts, starting with a slight excess of calcium phenylacetate, then using molecular proportions of the two, and, later, increasing the proportion of acetate.

(1) In the first distillation, 20 grams of calcium acetate, previously well dried by heating in an air-bath to 140°, were thoroughly mixed and ground in a mortar with 45 grams of dry calcium phenylacetate, the latter weight being 5 grams in excess of the calculated quantity required to form a molecular mixture.

The mixed salts were placed in a parting flask and heated to the temperature of boiling sulphur; a current of washed and dried carbon dioxide was passed through and maintained until the decomposition was complete. During the heating, there was just a little frothing, but although the mass became viscid and semi-transparent it did not become quite liquid. The ketone collected in the capillary tube in columns which were carried over into the receiver by the current of carbon dioxide. Towards the close of the distillation, the product became darker in colour and white fumes were formed which condensed with difficulty, forming a dark coloured oil.

Table I gives in the first column the weights of the three ketones

TABLE I.

Mols. Calcium Acetate : Calcium Phenylacetate : : 1 : 1·125.

Ketone.	Weight in grams.	Per cent.	Per cent. / mol. wt.	Per cent. number of mols.
$(CH_3)_2CO$	2	6·6	0·115	16·1
$\begin{matrix}CH_3\\C_7H_7\end{matrix}\!>\!CO$	18	60·0	0·448	62·5
$(C_7H_7)_2CO$	9	33·4	0·152	21·2

as estimated from the results of the fractional distillation. The second column gives the percentage weight of each ketone in the mixture, the third column this weight divided by the molecular weight of the ketone, and the last column the percentage number of molecules of each ketone.

(2) A second distillation was carried out in which molecular proportions of the calcium salts were employed, namely, 20 grams of calcium acetate to 40 grams of phenylacetate. The heating was effected precisely as in the preceding case, but the arrangements for condensing were improved, as it was thought there might have been a slight loss of acetone, due to its having been carried away by the carbon dioxide.

The crude distillate, after drying over ignited potassium carbonate, weighed 27 grams and on fractionation gave the figures set forth in Table II.

TABLE II.

Mols. Calcium Acetate : *Calcium Phenylacetate* : : 1 : 1.

Ketone.	Weight in grams.	Per cent.	Per cent. / mol. wt.	Per cent. number of mols.
$(CH_3)_2CO$	2	7·4	0·1276	17·7
$\begin{matrix}CH_3\\C_7H_7\end{matrix}\!>\!CO$	17	59·3	0·4430	61·4
$(C_7H_7)_2CO$	7	33·3	0·1514	21·3

These figures show that the greater part of the product is the benzyl methyl ketone. The calculated yield of this ketone, if none others were formed, would be 34 grams. Actually, 17 grams were obtained, so that when molecular proportions of the two calcium salts are taken, the yield of the mixed ketone is only 50 per cent. of the amount theoretically possible on the assumption that it was the only ketone formed.

In determining the proportion of the ketones present, rather more certainty would have been obtained if the method of mid-points had been employed (Young, Trans., 1902, **81**, 752). This was not known at the time, but, making allowance for some slight inaccuracy due to imperfect fractionation, the last column shows that *the number of molecules of mixed ketone is three times the number of molecules of either of the other two.*

The low figures for acetone would not permit the above statement to be made with much confidence were it not for the fact that some acetone must have been carried away by the rapid current of carbon dioxide. The weight of the dibenzyl ketone should be three times

that of the dimethyl ketone, whereas the figures obtained gave a ratio more nearly three and a half to one; but, as the number of molecules of dimethyl ketone produced should be equal to the number of dibenzyl ketone molecules, for the original mixture contained the two calcium salts in molecular proportion, it seems not only justifiable, but necessary, to assume that the acetone has been lost by evaporation.

(3) The next distillation was of a mixture containing 25 grams of calcium acetate and 35 grams of calcium phenylacetate. The ratio of molecules in such a mixture is 1·4 of the former to 1 of the latter. The results of the distillation are embodied in Table III. Unfortunately,

TABLE III.

Mols. Calcium Acetate : Calcium Phenylacetate : : 1·4 : 1.

Ketone.	Weight in grams.	Per cent.	$\frac{\text{Per cent}}{\text{mol. wt.}}$	Per cent. number of mols.
$(CH_3)_2CO$	4	17·4	0·2999	35·5
$\begin{matrix}CH_3\\C_7H_7\end{matrix}\!>\!CO$	13	56·5	0·4217	50·0
$(C_7H_7)_2CO$	6	26·1	0·1243	14·5

the total yield was only about 80 per cent. of that obtained in some of the other experiments, and the figures are of much less importance than those derived from experiments in which the total yield of crude unseparated ketones was greater.

(4) Two mols. of calcium acetate with one mol. of calcium phenylacetate. This molecular ratio is obtained almost exactly, if equal weights of the two salts are employed. In the actual experiments, 30 grams of each of the two salts were taken, ground together, and heated as before. The results obtained from one of these distillations are contained in Table IV, showing that the yield of acetone molecules

TABLE IV.

Mols. Calcium Acetate : Calcium Phenylacetate : : 2 : 1.

Ketone.	Weight in grams.	Per cent.	$\frac{\text{Per cent.}}{\text{mol. wt.}}$	Per cent. number of mols.
$(CH_3)_2CO$	8	25·8	0·445	48·0
$\begin{matrix}CH_3\\C_7H_7\end{matrix}\!>\!CO$	15·5	50·0	0·372	40·2
$(C_7H_7)_2CO$	7·5	24·2	0·11	11·8

in the distillate is approximately 50 per cent., and of the remainder four-fifths are of the mixed ketone and one-fifth dibenzyl ketone.

Preparation of Ethyl Benzyl Ketone.

As this ketone was not wanted in any considerable quantity for investigation, but only to serve as a check on results obtained with methyl and propyl benzyl ketones, between which it stands in the series, the calcium salts themselves are not so carefully purified, fewer distillations were carried out, and the final purification of the ketone was not so elaborate. The results are, in consequence, not strictly comparable with those obtained in the other two cases.

In point of time the experiments were not performed until several months after the preparation of the other two ketones had been completed and their investigation commenced

It was then found desirable to prepare this ketone, and see if it yielded derivatives possessing properties intermediate between those exhibited by the corresponding derivatives of the other two ketones, and this was found to be the case.

Twenty grams of calcium propionate, and 30 grams of calcium phenylacetate were mixed together and heated. Then the operation was repeated, and the crude distillate purified by fractionation.

In this case, the diethyl ketone boils at 103°, ethyl benzyl ketone at 227°, and dibenzyl ketone, as before, at 330°.

From 48 grams of crude distillate the three ketones were obtained as shown in Table V, and a further purification gave 12·5 grams of pure ethyl benzyl ketone.

TABLE V.

Mols. Calcium Propionate : *Calcium Phenylacetate* : : 1 : 1.

Ketone.	Weight in grams.	Per cent.	$\frac{\text{Per cent.}}{\text{mol. wt.}}$	Per cent. number of mols.
$(C_2H_5)_2CO$	5	12·5	0·1456	24·6
$C_2H_5 > CO$ ..... C_7H_7	20	50	0·2683	45·3
$(C_7H_7)_2CO$	15	37·5	0·1790	30·1

Preparation of Propyl Benzyl Ketone.

(1) Molecular mixtures of calcium butyrate (25 grams) and calcium phenylacetate (37 grams) were distilled in precisely the same manner as described under the preparation of methyl benzyl ketone. Three

distillations yielded the figures contained in the first three columns of Table VI, the fourth column being the means from which the figures

TABLE VI.

Mols. Calcium Butyrate : *Calcium Phenylacetate* : : 1 : 1.

Ketone.	Weight in grams.				Per cent.	Per cent. mol. wt.	Per cent. number of mols.	Per cent. number of mols.
	I.	II.	III.	Mean.				
$(C_3H_7)_2CO$	6	5	5	5·3	18·5	0·1626	25·6	22·4
$C_3H_7 > CO$	16	17	19	17·3	60·4	0·3734	58·7	60·1
C_7H_7								
$(C_7H_7)_2CO$	5	6	7	6	20·1	0·0998	15·7	17·5

in the succeeding columns are derived. In the last column, the percentage number of molecules is calculated from the last and best of the three distillations. It shows satisfactory agreement with the corresponding figures for methyl benzyl ketone.

(2) Two distillations were then made of a mixture containing 37 grams of calcium phenylacetate and 30 grams of calcium butyrate. This is in the proportion of one molecule of the former to 1·2 molecules of the latter, and the results are tabulated as before.

TABLE VII.

Mols. Calcium Butyrate : *Calcium Phenylacetate* : : 1·2 : 1.

Ketone.	Weight in grams.			Per cent.	Per cent. mol. wt.	Per cent. number of mols.
	I.	II.	Mean.			
$(C_3H_7)_2CO$.....	6	6	6	19·5	0·1697	26·5
$C_3H_7 > CO$	19	20	19·5	62·7	0·3883	60·4
C_7H_7						
$(C_7H_7)_2CO$	5	6	5·5	17·8	0·0845	13·1

In this case, as was to be expected, the percentage number of molecules of the lowest ketone has increased, that of the highest has decreased, but the middle ketone has not suffered diminution.

As this ketone had not been described, its exact boiling point was not known. A careful fractionation was accordingly performed, a "rod and disc" still-head being first employed, but later this was replaced by a "pear" dephlegmator possessing twelve bulbs. Finally, after seven distillations, a major fraction was obtained boiling between

243° and 244°, and the boiling point of the ketone consequently lies between these limits. The barometric pressure was 755 mm., and a very small Geissler thermometer was used, the whole of the column of mercury being immersed in the vapour of the boiling liquid. Since the above determination was made, the ketone has been obtained by an entirely different method (Blaise, *Compt. rend.*, 1901, 133, 1217), and the boiling point given is 238—241°.

This specimen is described as possessing the odour of aniseed, which is absent when prepared as described above, although the ketone has a characteristic odour.

Its density was d 0°/0° = 1·0090. Two determinations of its molecular weight in boiling benzene solution gave 164 and 161, whereas $C_3H_7 \cdot CO \cdot C_7H_7$ has the mol. wt. 162. The apparatus employed was a modification of Landsberger's, which forms the subject of the following note (p. 1193).

Mode of Decomposition of the Calcium Salts.

With regard to the mechanism of the changes which take place when the calcium salts of organic acids are heated, the figures obtained in the preparation of methyl benzyl ketone throw some light on the problem.

It is unlikely that absolute uniformity in the results could be obtained, however carefully a series of determinations was performed, and however thoroughly the two salts were ground and mixed. As already stated, the mass never becomes liquid, but the decomposition takes place when a pasty stage has been reached. At this stage, the formation of any one of the three possible ketones is determined by proximity. The results obtained indicate something of the nature of a selective affinity, bending towards the production of the mixed ketone in preference to the simple ketone.

Apart from this, the problem is apparently one of chances. Tabulating the ratio of the molecules of the salts originally taken and the molecular yields of ketones obtained, we obtain Table VII, which shows

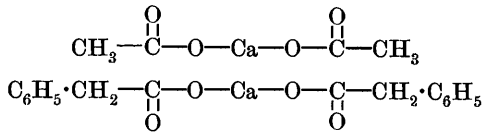
TABLE VIII.

Mols. calcium acetate : calcium phenylacetate.	Per cent. number of mols. of ketone obtained.		
	Dimethyl.	Methyl benzyl.	Dibenzyl.
1 : 1·125	16·1	62·5	21·5
1 : 1	17·7	61·4	21·3
1·4 : 1	35·5	50·0	14·5
2 : 1	48·0	40·2	11·8

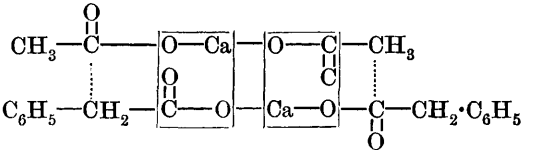
the effect that varying the proportion of the calcium salts has on the yield of the ketones.

An attempt to plot a probability curve failed owing to the small number and insufficient accuracy of the experimental values.

Writing the graphic formulæ of the calcium salts thus :



it may be considered that this represents something of the actual internal arrangement of the molecule, and, if the chain remains straight, or even approximately so, it is probable that the decomposition is in reality produced by the interaction of two molecules which have ranged up alongside each other, thus :



giving

$$2CH_3\cdot CO\cdot CH_2\cdot C_6H_5 + 2CaCO_3.$$

If this explanation is correct, the production of mixed ketone depends on the collisions between the molecules of the different salts, and these depend, firstly, on the mixing, inasmuch as the fusion is not complete, and, secondly, on the relative proportions of the two salts present.

It is clear that where molecular proportions have been taken the chances that the molecule of one salt will collide with a molecule of its own kind, or with a molecule of the other salt, are even. This being so, it would naturally be expected that half of the product would be mixed ketone, and the other half would consist of the simple ketones in molecular proportion, that is, the maximum yield of mixed ketone should be 50 per cent., and of the other two 25 per cent. each. Reference to Table VIII will, however, show that this is not the case, nor is there any close approximation to it. Consequently it seems probable that there is some directing force favouring the formation of the mixed ketone.

From a practical point of view, the figures in Table IX show that the best yield of mixed ketone obtainable from a given weight of the more expensive salt, in this case calcium phenylacetate, is obtained by using a large excess of the cheaper salt.

TABLE IX.

Experiment.	Weight of calcium acetate.	Weight of calcium phenylacetate.	Weight of mixed ketone obtained.	Weight of mixed ketone per 100 grams of calcium phenylacetate.
1	20	45	18	40
2	20	40	17	42·5
3	25	35	13	37
4	30	30	15	50
5	30	30	15·5	52

The increase in the yield shown in experiment 5 as compared with that in experiment 1 is sufficiently marked. The intermediate stages are fairly well represented by the figures as displayed, with the exception of experiment 3, owing to the fact that in this experiment the yield of all three ketones was poor. There is little doubt that the average of a number of experiments would have yielded a value nearer 45 than 37 when the errors due to a single experiment were eliminated.

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