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THE PREPARATION AND SOME REACTIONS OF CYCLOPROPYLDIAZOMETHANE AND CYCLOPROPYLMETHYLDIAZOTATE[1]

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Abstract—The synthesis of cyclopropyldiazomethane (CDM) is described. Hydrolysis of CDM with aqueous acid or base, or with distilled water afforded cyclopropylcarbinol, cyclobutanol, and allylcarbinol in a distribution similar to that observed in the aqueous nitrous acid deamination of cyclopropylcarbinylamine (i.e., cyclopropylcarbinyl/cyclobutyl was 1·0–1·4). Cyclopropylmethyldiazotate, I, afforded, upon hydrolysis, the same alcohols in a similar distribution. CDM was not an important precursor of the alcohols formed upon hydrolysis of I.

The esters formed upon reaction of CDM and of I with ethereal benzoic acid were investigated. Both reactions gave a mixture of cyclopropylcarbinyl, cyclobutyl, and allylcarbinyl benzoates. The mixture was rich in cyclopropylcarbinyl benzoate (i.e., cyclopropylcarbinyl/cyclobutyl was ca. 5–8). Reaction of I and ethereal benzoyl chloride afforded the same esters in a similar distribution, and also, N-cyclopropylmethyl-N-nitrosobenzamide as a minor product. Thermolysis, in ether, of the nitrosamide also afforded the benzoate esters in a similar distribution. Intermediates capable of accounting for the products and their distribution are discussed.

Despite Adamson and Kenner's extensive preparative studies of diazomethane and its higher homologs, cyclopropyldiazomethane (CDM) proved elusive.[2] An attempt to prepare CDM from cyclopropanecarboxyaldehyde tosylhydrazone afforded the desired product in less than 5% yield.[3] In both attempted preparations, product instability under the conditions used to decompose the diazoalkane precursor appeared to be the problem. By way of contrast, preparations of diazocyclobutane[4] and allyldiazomethane,[5] skeletal isomers of CDM, had been reported.

Our interest in diazo and diazotate chemistry prompted us to undertake new experiments toward the preparation of CDM. The successful outcome of those experiments has been communicated.[6*] Presently we wish to describe several alcohol- and ester-forming decompositions of CDM and related compounds. The significance of the observed kinetically-controlled product distributions will also be discussed. Consideration of the hydrocarbon products of these reactions will here be deferred, though possible contributions of these products to the present results will be indicated.

RESULTS AND DISCUSSION

Preparation of cyclopropyldiazomethane. CDM was prepared by the sequence outlined in Chart I.

Chart I

$$\text{R-CN} \rightarrow \text{R-CH}_2\text{—NH}_2 \rightarrow \text{R-CH}_2\text{—NH—COOC}_2\text{H}_5 \rightarrow$$
$$\text{R-CH}_2\text{—N(NO)—COOC}_2\text{H}_5 \rightarrow \text{RCH=N}_2$$
$$\text{R} = \text{Cyclopropyl.}$$

* Other groups were simultaneously developing preparations of CDM.[7]

Commercially available cyclopropyl cyanide was reduced with LAH. The amine thus obtained was treated with ethylchloroformate, giving N-cyclopropylmethylurethan, which was then nitrosated with ethereal nitrogen tetroxide. Decomposition of the ultimate precursor, N-cyclopropylmethyl-N-nitrosourethan, was effected with a freshly prepared solution of sodium triethyleneglycolate in triethyleneglycol. At a reaction temperature of $-25°$, and under reduced pressure (1–2 Torr), product CDM distilled as formed, and was condensed at $-78°$. It was purified by trap-to-trap distillation.

In the IR, CDM exhibited a characteristic[8] diazo absorption (2070 cm^{-1}). CDM was further characterized by its extremely rapid reaction with cold benzaldehyde, which afforded α-cyclopropylacetophenone.*

Reaction of CDM with water. The reaction of a diazoalkane with aqueous mineral acid should yield a hydrated alkyldiazonium ion. Since the same ion is presumably involved in the aqueous nitrous acid deamination of the corresponding alkyl amine, the general expectation is for similar product distributions in the two reactions.[10,11]

Roberts has reported that the aqueous nitrous acid deamination of cyclopropylcarbinylamine leads to cyclopropylcarbinol, cyclobutanol, and allylcarbinol.[12] This reaction presumably involves the formation of cyclopropylmethyldiazonium ion and thence a cationic intermediate represented by Roberts as an equilibrating mixture of bicyclobutonium cations.[12] The reported product distribution appears in Table 1 (case 1). Our repetition of this deamination gave similar but not identical results (case 2).

The addition of 10^{-4}M aqueous perchloric acid to CDM gave a product mixture containing the anticipated C_4 alcohols. The cyclopropylcarbinol/cyclobutanol ratio was close to unity (case 3). A similar result (case 4) was obtained when CDM was stirred with distilled water. This reaction was noticeably slower than the acid-catalyzed decomposition which appeared to be instantaneous. Decomposition of CDM with 1N aqueous sodium hydroxide was very slow, requiring ca. 30 min, and afforded the alcohols with a somewhat higher cyclopropyl/cyclobutyl ratio (case 5).

There are variations in product distribution for cases 1–5 of Table 1. Control experiments showed that these were not due to product isomerization under the various experimental conditions. These variations must, therefore, have some non-trivial significance. Indeed, noting that the cyclopropylcarbinol/cyclobutanol ratio from aqueous nitrous acid deamination of cyclopropylcarbinylamine was greater than that observed in a similar deamination of cyclobutylamine, Roberts suggested that there could be a small S_N2 component in the former deamination.[12] However, in a later appraisal of the data, with which we are inclinded to agree, he held that a diazonium ion-carbonium ion mechanism was required for the various deaminations and that, "... small variations in product composition may be accounted for by specific effects of each reaction and do not require postulation of a drastic change in mechanism."[13] Under this conception, and in the light of other decomposition experiments with CDM (see below), we suggest that, in water, CDM is, in large part, transformed to the same system of diazonium-carbonium ion intermediates which

* Related reactions of diazoalkanes have been surveyed.[9]

TABLE 1. ALCOHOLS FROM CYCLOPROPYLCARBINYLAMINE, CDM, AND CYCLOPROPYLMETHYLDIAZOTATE[a]

Case	Reaction	Cyclopropylcarbinol, %	Cyclobutanol, %	Allylcarbinol, %	▷ CH_2OH/□ OH
1.[b]	Cyclopropylcarbinylamine + HNO_2, 0°	56·0	40·4	4·1	1·39
2.[c]	Cyclopropylcarbinylamine + HNO_2, 0°	52·3	44·8	2·8	1·17
	Cyclopropylcarbinylamine + HNO_2, 0°	52·1	44·4	3·5	1·16
3.	CDM + 10 $^{-4}$ M $HClO_4$, −40°	49·4	48·6	2·2	1·02
4.	CDM + distilled H_2O, 0°	48·9	46·4	4·7	1·05
5.	CDM + 1N NaOH, 0°	53·5	42·8	3·7	1·25
6.	Diazotate I + $H_2O(OH^-)$, −40°	55·8	44·2	*d*	1·26
	Diazotate I + $H_2O(OH^-)$, −40°	56·5	43·4	*d*	1·30[e]
7.	Diazotate I + $D_2O(OD^-)$, −40°	55·3	44·8	*d*	1·23
	Diazotate I + $D_2O(OD^-)$, −40°	54·5	45·5	*d*	1·20
	Diazotate I + $D_2O(OD^-)$, −40°	58·6	41·4	*d*	1·42[e]

[a] The alcohols were separated and analyzed by VPC on a 20 ft, 0·25 in, 10% 1,2,3-tris (2-cyanoethoxy)propane on 45/60 Gas-Chrom R column at 120°. They were identified by comparison of their retention times and NMR spectra with those of authentic samples. In some cases, reaction mixtures were quantitatively benzoylated, and duplicate analyses were carried out on the corrresponding benzoates. These analyses were satisfactory.

[b] Ref. 12.

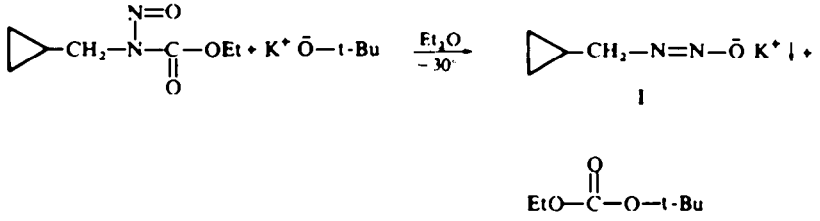
[c] This work.

[d] Allylcarbinol could not be directly determined because it was not separable from the carbonate mixture (see text) under our conditions. However, benzoylation of the reaction product, followed by VPC analysis of the benzoates indicated that it had been present to 5·6% of the alcohol mixture. In the Table, the cyclopropylcarbinol and cyclobutanol are normalized to 100%.

[e] In this experiment, ether and carbonates (>95%) were removed by vacuum distillation prior to hydrolysis. The data are for the hydrolysis of dry diazotate I, rather than for an ethereal slurry of I.

arises in the aqueous nitrous acid deamination of cyclopropylcarbinylamine.[12] In this, it behaves as a normal diazoalkane.*

As an extension of these experiments, we studied the basic hydrolysis of cyclopropylmethyldiazotate, I. This species was produced from ethereal N-cyclopropylmethyl-N-nitrosourethan by cleavage with potassium-t-butoxide (Eq. 1).[15] That I was the product of this reaction is indicated by: (a) analogy



(1)

to our previous studies of this type of reaction;[1,15] (b) the formation of a high yield of dialkylcarbonate (>90%), product of acyl attack of t-butoxide on the nitrosourethan;† (c) the observation that no nitrogen evolution attends reaction (1), but that such evolution is immediately observed upon hydrolysis of the reaction mixture; (d) the observation that the dialkylcarbonate formed in reaction (1) can be removed by vacuum distillation *prior* to hydrolysis (isolated yield, 70%) in which case the product distribution and gas evolution attending hydrolysis are unchanged except for the absence of carbonates (<5%); (e) the results of other decompositions of I (see below).

Hydrolysis of an ethereal slurry of the diazotate I resulted in 80–100% nitrogen evolution within several seconds. A C_4 alcohol mixture could then be isolated in 30-40% yield (based on I). The alcohol product distribution appears in Table 1 (case 6). The diazotate hydrolysis was carried out in the presence of an extra equivalent of potassium t-butoxide, and thus proceeded under highly basic conditions. It is therefore interesting to note the similar alcohol distributions for the basic hydrolyses of I (case 6) and CDM (case 5).

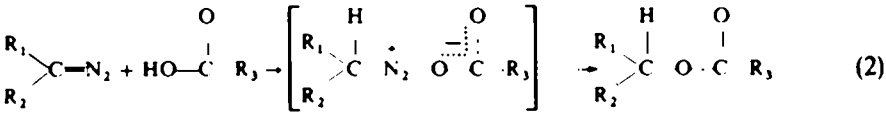
Our previous work has shown that primary alkyl diazotates partition between "carbonium ion" products and diazoalkanes upon basic hydrolysis.[15] We therefore inquired whether CDM was a precursor of the alcohols arising from I. The hydrolysis of I with deuterium oxide afforded the expected alcohols with the distribution cited in Table 1 (case 7). Cyclopropylcarbinol and cyclobutanol were isolated by preparative VPC and examined in the NMR. Relative to a benzene (or pyridine) internal standard, integration of the various proton signals of either alcohol showed that 5–10% (3%) of one deuterium atom had been incorporated. CDM was, therefore, at most, only a minor precursor of the alcohols generated by the basic hydrolysis of

* In the above, we have not considered the possibility that hydrocarbon products such as bicyclobutane and/or cyclobutene are significant alcohol precursors. For bicyclobutane, at least, this would not affect the conclusions, since hydration of that alkane leads to an alcohol distribution similar to those gathered in Table 1.[14]

† The significance of this observation has been brought out by Jones and Muck.[16] Leading Refs to related literature are gathered in footnote 7 of Ref 1.

I.* At present, then, it seems simplest to conclude that the diazotate hydrolysis occurs *via* cationic intermediates *similar* to those involved in the CDM hydrolysis and in the deamination of cyclopropylcarbinylamine (see above).

Reactions of CDM and related species with benzoic acid. In contrast to their reactions with aqueous mineral acid, the reaction of diazoalkanes and carboxylic acids in non-polar solvents does not lead to free alkyldiazonium ions. Rather, there is formed an intimate diazonium-carboxylate ion pair which, with loss of nitrogen, can collapse directly to an ester. Intermediates in which carbon skeleton rearrangements and/or hydride shifts (e.g., carbonium ions and/or perhaps solvated diazonium ions) can occur may thus be bypassed, and the ester products of these reactions generally contain alkyl residues which are not rearranged relative to the original diazoalkane.[2,10] This process is outlined in (Eq. 2).



(2)

Thus, although either 1-diazo-2-butene or 3-diazo-1-butene reacts with aqueous perchloric acid to yield the same mixture of crotyl alcohol and methylvinylcarbinol obtained from aqueous nitrous acid deamination of either analogous amine, either diazoalkene affords only unrearranged ester upon reaction with ethereal 3,5-dinitrobenzoic acid.[11a] Similarly, the reaction of 1-diazopropane with benzoic acid in benzene led to a high yield of n-propyl benzoate, contaminated with less than 2% of i-propyl benzoate, whereas the action of aqueous perchloric acid on the diazoalkane led to a propanol mixture containing 28·1% of isopropanol. (Deamination of n-propylamine with aqueous nitrous acid afforded a similar propanol mixture.)[11b]

Nevertheless, the absence of alkyl rearrangement in the reaction of diazoalkanes and carboxylic acids is not the invariable observation. In sufficiently polar solvents, ion pairs [as depicted in (2)] can become solvent separated, in which case rearranged esters can be formed.[11b] Alternatively, if sufficient driving force for rearrangement is built into the alkyl system of the diazoalkane, or if that alkyl system ultimately affords a carbonium ion of special structure (e.g. a cyclopropylcarbinyl or cyclobutyl cation), then rearrangement can occur even in ether, presumably within the ion pair. Thus, from the reaction of 2-diazo-1,1,1-triphenylethane with ethereal benzoic acid, 1,1,2-triphenylethyl benzoate was isolated.[17] Similarly, diazoneopentane reacted with ethereal 3,5-dinitrobenzoic acid to yield trimethylethylene and an ester mixture in which the t-amyl/neopentyl ratio was 4.3.[11a] †

The previous work most relevant to our own studies is that of Applequist and McGreer.[4] From the reaction of diazocyclobutane in ca. 98% toluene-2% ethanol with *p*-phenylazobenzoic acid, these authors isolated (among other products) cyclopropylcarbinyl and cyclobutyl *p*-phenylazobenzoates in the ratio 1·27/1·00. The ester ratio was solvent dependent; from a similar reaction in ca. 99% ether–1%

* Bicyclobutane is similarly excluded as an important alcohol precursor in this decomposition. The minor importance of diazoalkane in the hydrolysis of I, as compared to other primary diazotates, is probably a reflection of the special nature of the "primary" carbonium ion derived from I. See the discussion in Ref. 15.

† See the recent and valuable extension of this work.[18]

TABLE 2. BENZOATES FROM CDM, CYCLOPROPYLMETHYLDIAZOTATE, AND N-CYCLOPROPYLMETHYL-N-NITROSOBENZAMIDE[a]

Case	Reaction	Cyclopropylcarbinyl benzoate, %	Cyclobutyl benzoate, %	Allylcarbinyl benzoate, %	>—CH2/
1.	CDM + C_6H_5COOH, Ether, 40°	79·2	13·6	7·2	5·82
2	CDM + C_6H_5COOH 98% Toluene + 2% Ethanol, 40°	78·9	13·4	7·8	5·89
3.	CDM + C_6H_5COOH, Chloroform, −40°	78·0	12·3	9·8	6·34
4.	CDM + C_6H_5COOH, Ether saturated with water, −40°	79·0	12·6	8·4	6·27
5.	I + C_6H_5COOH, Ether, −40°	83·5	11·7	4·8	7·14
	I + C_6H_5COOH, Ether, −40°	84·7	10·9	4·4	7·77
	I + C_6H_5COOH, Ether, −40°	83·7	12·4	3·9	6·75[b]
	I + C_6H_5COOH, Ether, −10°	85·6	10·3	4·1	8·31
6.	I + C_6H_5COCl, Ether, −10°	78·2	12·8	9·0	6·10
	I + C_6H_5COCl, Ether, −10°	78·2	13·8	8·0	5·66
7.	V, Ether, 25°	74·6	12·9	12·6	5·78

[a] The esters were separated and analyzed by VPC on the same column used for the alcohols (Table 1, footnote *a*) at 160°. They were identified by comparison of their retention times and NMR spectra with those of authentic samples.

[b] Benzoic acid 0-d.

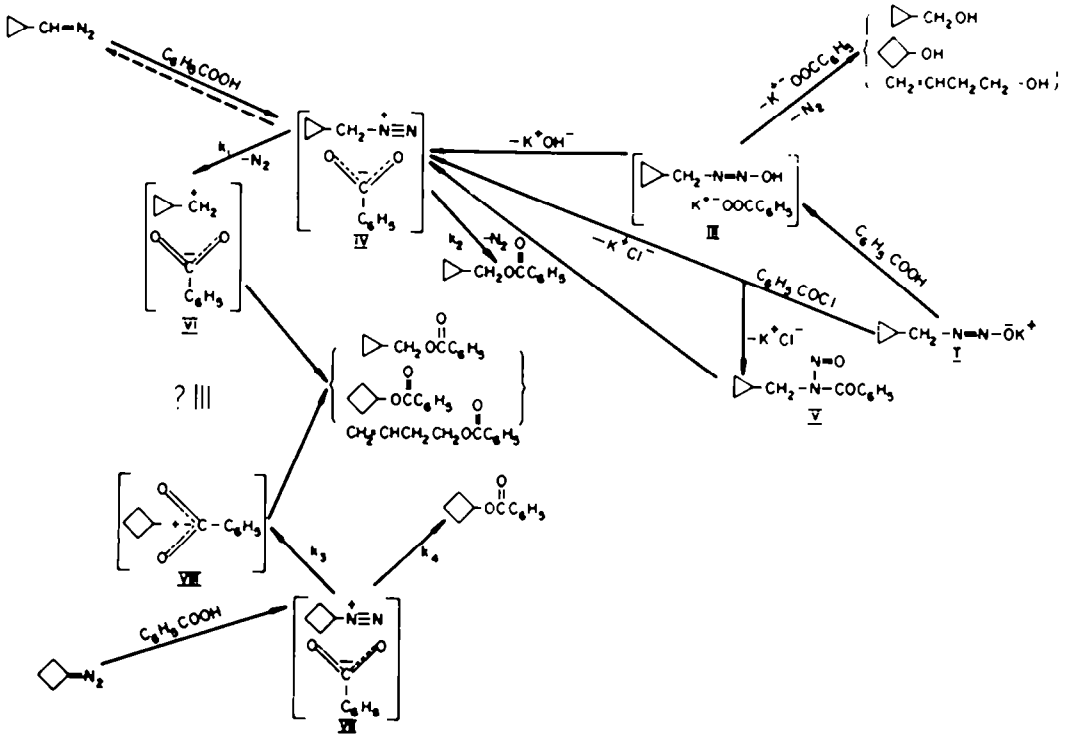
ethanol the ester ratio was 0·96/1·00. The authors suggested that the bicyclobutonium-carboxylate ion pair, II, was ultimately formed in these reactions, and that this species largely accounted for the observed products.

II

Upon addition of excess ethereal benzoic acid to CDM at ca. −40°, we observed a rapid bleaching of the diazoalkane's characteristic red colour, accompanied by gas evolution. From the resulting ethereal solution, we isolated 29% of the theoretical yield of an ester mixture consisting of cyclopropylcarbinyl benzoate, cyclobutyl benzoate, and allylcarbinyl benzoate. The ester distribution appears in Table 2 (case 1). It is immediately apparent that there has been a great decrease in carbon skeleton rearrangement in this reaction, compared to that observed in the hydrolyses of CDM discussed above. Other solvent systems were investigated with rather similar results (cases 2–4).

Chart II has been constructed as an abridged *guide* to the reactions now under consideration. Several possible intermediates have been omitted for the sake of brevity, and we do not consider it to have definitive mechanistic significance.

CHART 2



With reference to the chart, the reaction of CDM and benzoic acid presumably leads to ion pair IV. The activation energy for nitrogen loss from alkyldiazonium ions is low.* As a result, several kinds of nitrogen-loss decompositions of IV could be competitive. In particular, direct collapse of IV might occur *via* a kind of "S_N2" displacement of nitrogen by the benzoate oxygen within the oriented[11b] ion pair, k_2. This pathway would yield only cyclopropylcarbinyl benzoate, and would be competitive with leakage to ion pair VI, k_1, from which all three esters might arise (pathway A).†

On the other hand, diazonium ion pair IV might eschew ester formation and follow an "S_N1" nitrogen loss pathway exclusively, $k_1 \gg k_2$, yielding ion pair VI. The observed product distribution would then reflect the peculiarities of a cyclopropylcarbonium ion strongly "solvated" by the benzoate anion in a relatively non-polar solvent (pathway B).‡

With regard to these possibilities, it is significant that the ester distribution from the reaction of CDM and a carboxylic acid differs from that found in the reaction of diazocyclobutane and a carboxylic acid. The former reaction leads to ester mixtures rich in cyclopropylcarbinyl structure; the latter reaction leads to mixtures in which the cyclopropylcarbinyl/cyclobutyl ratio is much nearer unity.[4] Now there are other reactions of cyclopropylcarbinyl derivatives which are known to afford reaction products with a high degree of skeletal retention.[21] Another example is the reaction of cyclopropylcarbinol with thionyl chloride.[22] But, in this case, *both* cyclopropylcarbinol and cyclobutanol afford a similar mixture of alkyl chlorides. It might be argued that the CDM-benzoic acid results differ from the diazocyclobutane-*p*-phenylazobenzoic acid results because of the difference in carboxylic acid. However, in unpublished work, Friedman has shown that, even when treated with the same carboxylic acid (acetic acid), CDM and diazocyclobutane lead to very different cyclopropylcarbinyl/cyclobutyl ratios (4·5 and 1·4, respectively).§ It follows that CDM and diazocyclobutane react with carboxylic acids, at least in part, *via* different pathways. The ideas conveyed in pathway A (see above) can serve as a presently adequate rationale. The ion pair, VII, directly arising from diazocyclobutane and a carboxylic acid (e.g., benzoic acid), will differ from IV. It is reasonable to expect that partition of VII between the pathways denoted by k_3 and k_4 will lead to a product distribution different than that resulting from partition of IV between the pathways denoted by k_1 and k_2. Indeed, one might expect that, for the primary diazonium ion IV, direct "S_N2" collapse, k_2, will contribute more importantly to the partition than the analogous pathway, k_4, will contribute to the partition of VII.[19] Hence, the differences in the reactions of CDM and diazocyclobutane with carboxylic acids may be due largely to the differences in diazonium carboxylate ion pairs initially formed in each case. After the diazonium stage, similar intermediates might arise in each case, *i.e.*

* See the discussion in Ref. 19 and Refs. 10 and 11*b*.

† Another pathway for direct formation of cyclopropylcarbinyl benzoate involves nitrogen loss concerted with proton transfer from the benzoic acid; this and other alternatives are discussed for phenyldiazomethane-trifluoroacetic acid decompositions.[20] The discussion here will follow the more traditional ion-pair mechanism.[10]

‡ It is known that the solvolysis of cyclopropylcarbinyl tosylate in acetic acid gives an ester mixture quite rich in cyclopropylcarbinyl acetate.[21]

§ Private communication from Professor Lester Friedman, Case Institute of Technology, 27 April 1967.

VIII and VI might be considered identical, and better represented by a non-classical cyclopropylcarbinyl cation-benzoate pair.*

Turning now to related reactions, it was with considerable interest that we observed benzoylation of diazotate, I, by benzoic acid. Addition of excess ethereal benzoic acid to I led instantly to essentially quantitative gas evolution. From the product mixture, we isolated 29% of the theoretical yield of benzoate esters with the distbution shown in Table 2 (case 5), and a 10% yield of the corresponding alcohols. (The cyclopropylcarbinol/cyclobutanol ratio was 3·50). A control experiment (in which a known mixture of the benzoate esters, together with excess benzoic acid in ether, was injected into an ethereal slurry of potassium-t-butoxide at $-40°$) demonstrated both that the alcohols did not arise from the esters under the reaction conditions, and that the esters were stable under the reaction conditions.

A rationalization of these results can be given, with reference to Chart II. The reaction of I with benzoic acid produces diazotic acid, III, and potassium benzoate. III can decompose directly to alcohols. As formed here, in the absence of extensive hydration, III is not chemically equivalent to the species formed when I is drowned with water (see above). This latter reaction leads to a product mixture in which cyclopropylcarbinol/cyclobutanol is 1·26.† Alternatively, by loss of potassium hydroxide, III may go over to IV, ultimately yielding a benzoate mixture very rich in cyclopropylcarbinyl benzoate. We have no simple explanation for the greater skeletal retention here as compared to the CDM-benzoic acid reaction.‡

After diazotate I had been decomposed with four-fold excess ethereal O-deuterated benzoic acid (at least 95% deuterated by NMR), mass spectral examination of the isolated esters showed the cyclopropylcarbinyl benzoate to be 10·4% d_1 and 0·4% d_2; the cyclobutyl benzoate was 8·2% d_1 and 0·0% d_2. The results are consistent with some formation of CDM from III and/or IV. They are also consistent with the intervention of some bicyclobutane as precursor for the esters. The observed deuterium incorporation represents only a minimum for the alternate pathways, since formation of CDM and/or bicyclobutane would correspondingly yield some benzoic acid–O—H, thus diluting the deuterated acid pool. Since there might be a substantial isotope effect in the ester forming reactions,§ it is difficult to closely estimate an upper limit

* It should be noted that some bicyclobutane could arise from IV, (this would represent a type of "aprotic diazotization")[23] and that under the reaction conditions some of this hydrocarbon could be converted to a benzoate ester mixture. This pathway, however, would funnel through VI. (It is known that the cyclopropylcarbinyl-cyclobutyl distribution in such an ester mixture will be similar to that observed for the reaction of CDM and a carboxylic acid, and markedly different from that resulting from diazocyclobutane and a carboxylic acid.) Under the conditions here employed, this alternate pathway to esters is likely to be very minor (*see below*).

† One interpretation holds that, in water, leakage by nitrogen loss to a hydrated cyclopropylcarbinyl cation is relatively complete, and ultimately leads to nearly equal amounts of cyclopropylcarbinol and cyclobutanol. However, the unhydrated diazotic acid, III, formed from I and ethereal benzoic acid, collapses in large part *via* intimate ion pairs. (Direct evidence for alcohol formation from such ion pairs during diazotate hydrolysis has recently been obtained.[1]) It is interesting to note the approach of the cyclopropylcarbinyl/cyclobutyl ratio from this reaction to that of the CDM-benzoic acid reaction.

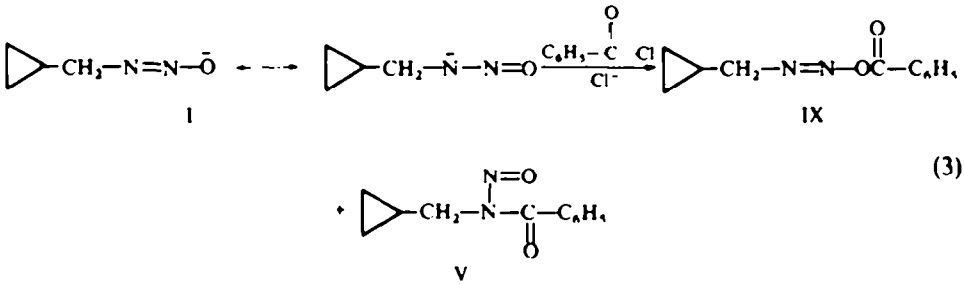
‡ Other than the possibility of some S_N2 attack of benzoate ion on III, S_N2 components in the decomposition of related intermediates in similar circumstances are known,[24] but we do not insist on this explanation.

§ Isotope effects in the reaction of benzoic acid and diphenyldiazomethane have been discussed,[25] but see Ref. 26.

for the alternate pathways. However, taking account of the relatively low extent of incorporation in crude estimates does suggest that the CDM and/or bicyclobutane pathways are minor contributors to product formation.

Diazotate I also reacted with benzoyl chloride. At $-10°$, gas evolution was immediate and about 60% of the theoretical. The product mixture yielded 33% of the anticipated benzoates, in the distribution recorded in Table 2 (case 6), as well as about 10% of N-cyclopropylmethyl-N-nitrosobenzamide, V.*

Diazotate, I, is an ambident anion, and its reaction with an acid chloride could lead to two products (eq. 3).†



(3)

Diazoester, IX, is a covalent form of ion pair IV, and should rapidly collapse to the same benzoate mixture observed in the reaction of CDM and benzoic acid. The data support this expectation. (Compare Table 2 cases 1 and 6). Moreover, N-alkyl-N-nitrosamides, such as V, can be thermally rearranged to diazoesters.[28] Thus, at room temperature, the product mixture from the reaction of I and benzoyl chloride slowly evolves nitrogen as the V it contains is converted to IX, and, ultimately, through ion pair IV, to the benzoate ester mixture. Indeed, when V (prepared by nitrosation of N-cyclopropylmethylbenzamide) was stirred in ether at (ca. 25°), 96% of the theoretical gas evolution was observed, and a 57% yield of benzoates could be recovered. The product distribution was very similar to those observed in the reactions of I with benzoyl chloride and of CDM with benzoic acid (Table 2, cases 1, 6 and 7).

Diazoesters derived from N-alkyl-N-nitrosamides can fragment to diazoalkanes and carboxylic acids (and thence to esters) competitively with their direct collapse to esters and nitrogen.[28] When V was decomposed in an ethereal solution containing 10-fold excess deuteriobenzoic acid, the resulting esters, as revealed by mass spectroscopy, contained much deuterium. The cyclopropylcarbinyl benzoate was 32·3% d_1, and 12·9% d_2; the cyclobutyl benzoate was 28·1% d_1 and 8·3% d_2. Traces of d_3 species were observed. Although these results are subject to the reservations discussed above (for the reaction of I and benzoic acid-O-d), in view of the large excess of deuterobenzoic acid used, they probably closely reflect the true extent of incursion of

* Identification of this compound rests on the fact that, after subtracting out signals arising from the esters, the NMR spectrum of the solvent-free crude product mixture exhibited the unique carbinyl doublet of authentic V.

† A similar reaction and related Refs have been discussed.[27]

those pathways for which deuterium incorporation is possible. By analogy to previous work,[28] the results are most easily rationalized by extensive CDM formation from V. This is depicted in Chart II as funneling through IV, but diazoester IX is presumably a prior intermediate,[28] and could eliminate benzoic acid without going to IV. The dideuterated esters could have arisen via reaction of bicyclobutane-d_1, formed from CDM and deuterobenzoic acid; or, if IV can revert to CDM and benzoic acid, these esters could have originated in a reaction of CDM-d_1 with deuterobenzoic acid. In view of the rate-determining nature of proton transfer between benzoic acid and other diazo compounds,[25] the CDM-d_1 pathway may seem less likely, but recent studies of isobutylamine deaminations[26] make it apparent that CDM is the only intermediate which need be invoked to account for the dideuterated esters. Control experiments established that the cyclopropyl and cyclobutyl benzoates (and presumably V) did not incorporate deuterium under the reaction conditions.

The intervention of CDM appears to be more important in the thermolysis of V than in the reaction of I and benzoic acid (see above), perhaps because the elimination of benzoic acid from IX or IV competes more successfully with nitrogen-loss pathways at 25° than at −40°.

EXPERIMENTAL

Cyclopropyldiazomethane. To a stirred suspension of 30·3 g (0·8 mole) LAH in 500 ml of ether, was added 50·0 g (0·75 mole) cyclopropyl cyanide (Aldrich) at a rate sufficient to maintain gentle reflux. After the addition was finished, 50 ml EtOAc was introduced, followed by water until the reaction mixture just turned white. The ethereal phase was decanted. The remaining slurry was repeatedly extracted with ether. Combination of the ether solns was followed by drying over $MgSO_4$. The solvent was removed by distillation; then product was distilled at 83°, affording 35·0 g of a water-white liquid with a characteristic amine odor. The amine was not characterized further, but directly converted to N-cyclopropylmethylurethan according to the standard procedure.[29] There was ultimately obtained 26·0 g of the desired urethan, b.p., 115°/15 mm. IR: 5·90 μ (neat, carbonyl). NMR: 5·48–5·88, broad M (N—H); 4·03, Q, J = 7 c/s. (O—CH_2); 2·98, T, J = 6·5 c/s. (CH_2—N); 1·21, T, J = 7 c/s. (—CH_3) superimposed on 1·50–1·05, M (cyclopropyl methine); 0·72–0·10, M (cyclopropyl).* (Found: C, 58·69; H, 9·23; N, 9·45. Calc. for $C_7H_{13}NO_2$: C, 58·72; H, 9·15; N, 9·78%.)† The yield of the clear liquid was 24% based on the starting cyclopropyl cyanide. Most of the material loss occurred in the reduction step. Experiments with isolated amine allowed conversions to urethan of 95%.

Nitrosation of the urethan was carried out in a manner similar to that of White.[30] To a stirred mixture of 11·3 g of sodium bicarbonate, 12·8 g (0·089 mole) of the urethan, and 40 ml of ether, maintained at −30 ± 5° under a nitrogen atmosphere, was slowly added a soln of 13·5 g (0·15 mole) nitrogen tetroxide in 18 ml ether. After 1·25 hr, the reaction mixture was warmed to 0°, diluted with 30 ml ether, washed 5 times with 10% $NaHCO_3$ aq, and dried over Na_2SO_4. The solvent was stripped, affording 13·4 g of N-cyclopropylmethyl-N-nitrosourethan, a yellow oil. IR: 5·75 μ (neat, carbonyl). NMR: 4·43, Q, J = 7 c/s. (O—CH_2); 3·50, D, J = 7 c/s. (CH_2—N); 1·43, T, J = 7 c/s. (—CH_3) superimposed on 1·40–0·98, M (cyclopropyl methine); 0·56–0·10, M (cyclopropyl).‡

Sodium (1·3 g; 0·056 moles) was dissolved in 30 ml triethylene glycol. The resulting soln was stirred and maintained at −25°. After evacuation to 1–2 Torr, 5·6 g (0·032 mole) of the nitrosourethan was injected through a serum cap, in 0·5 ml portions, over a period of 1 hr. CDM distilled from the reaction mixture as

* NMR spectra were determined as CCl_4 solns with Varian A-60 equipment. Signals are reported in ppm downfield from internal TMS; D = doublet, T = triplet, Q = quartet, M = multiplet. Assignments are indicated in parenthesis. Unless otherwise indicated, all signals displayed approximately correct integral areas.

† All microanalyses were done by Micro-Tech Laboratories, Skokie, Illinois.

‡ The identity of the nitrosourethan is clearly established by the comparison of its NMR with that of its urethan precursor.[31]

it formed, and was collected in a trap at −78°. The trap was warmed to −20° and the system press was reduced to 0·25 Torr. CDM was thus distilled into a second trap, cooled to −78°. The distillation was repeated a second time. CDM was obtained as a red-orange liquid, possessing a strong garlic odor. IR: 2070 cm^{-1} ($CDCl_3$ solution, plastic cell).*

Reaction of CDM with benzaldehyde. The trap containing the final product of the above CDM preparation was connected to a gas buret, and 3·4 g (0·032 mole) benzaldehyde (cooled to −15°) was added. There was immediate evolution of 24% of the theoretical gas content (based on the starting N-nitrosourethane). The reaction product was washed out with ether. Stripping of solvent afforded 4·10 g liquid, which was treated twice with sat $NaHSO_3$ aq. The resulting residue was extracted with ether. The ether soln was dried over $CaSO_4$ and stripped of solvent leaving 0·55 g of oil. A portion (100 mg) was purified on an F and M model 500 gas chromatograph using a carbowax 20 M column at 185°. The product was identified as α-cyclopropylacetophenone. IR: 5·95 μ (neat, carbonyl). NMR: 7·90–7·69, 7·49–7·12, M (aromatic); 2·78, D, J = 6·5 c/s. (methylene); 1·10, M (cyclopropyl methine); 0·80–0·00, M (cyclopropyl). A 2,4-dinitrophenylhydrazone was prepared, m.p., 155–156° from EtOH. (Found: C, 56·69; H, 4·93; N, 16·42. Calc. for $C_{17}H_{16}N_4O_4$: C, 59·99; H, 4·74; N, 16·46%.) Analysis of the VPC trace (which also indicated some residual benzaldehyde) showed that α-cyclopropylacetophenone had been formed in 13% yield (based on the starting N-nitrosourethan).

The remainder of the α-cyclopropylacetophenone was reduced with LAH, in a standard manner, to afford cyclopropylcarbinylphenylcarbinol. The latter was identical (IR and NMR) with an authentic sample.[32]

Deamination of cyclopropylcarbinylamine. To a 100 ml flask, cooled in an ice bath, was added 2·10 g (0·030 mole) of cyclopropylcarbinylamine, 34 ml of 1N perchloric acid, and 20 ml of water. A soln of 7·18 g (0·10 mole) $NaNO_2$ in 20 ml water was then added, with stirring, over 5 min. After 30 min the reaction mixture was distilled and 20 ml of distillate was collected. The distillate was saturated with K_2CO_3 and continuously extracted with 35 ml ether for 24 hr. The extract was dried (K_2CO_3). VPC analysis showed the presence of cyclopropylcarbinol, cyclobutanol, and allylcarbinol.* The alcohols were identified by comparison of retention times and NMR spectra with those of authentic materials. The alcohol distribution is reported in Table 1 (case 2).

Reactions of CDM with aqueous solutions. These reactions (cases 3–5, Table 1) were carried out by addition of the indicated reagent to the twice-distilled CDM resting in the final cold trap. It was not possible to have real control over reaction temp.† The reaction mixture was warmed to room temp, saturated with potassium carbonate, and extracted with ether. Most of the ether (after drying) was removed by careful distillation, and the residue was analyzed by VPC.* The product distributions of the various experiments are recorded in Table 1. Products were identified by satisfactory comparison of VPC and NMR data with those of authentic samples.*

Reaction of CDM with benzoic acid. This reaction was carried out by adding excess benzoic acid in ether to the CDM prepared as above. At least 1 equiv of benzoic acid was used for each equiv of the N-cyclopropylmethyl-N-nitrosourethan used in preparing the CDM. Reaction mixtures were washed with 10% $NaHCO_3$ aq, dried over Na_2SO_4, and stripped of solvent. In most cases, the reaction mixture was first submitted to VPC without removal of solvent to see if any C_4 alcohols were present. The results of the benzoic acid experiments are discussed above, and product distributions are reported in Table 2 (cases 1–4). The benzoate esters were analyzed and isolated using the previously described* VPC equipment, with a column temp of 160°. (A prepared product mixture was analyzed with good accuracy.) The ester products were identified by comparison of VPC and NMR data with those of authentic samples.

Cyclopropylcarbinylbenzoate. To a soln of 1·0 g (0·014 mole) cyclopropylcarbinol (Aldrich) in 10 ml of pyridine was added dropwise 1·2 g (0·0086 mole) benzoyl chloride. After the reaction mixture had been stirred for 5 min, it was poured into 50 ml water. The aqueous mixture was extracted with 50 ml ether, and

* VPC analysis for the alcohols was carried out on an Aerograph, A90 P3, instrument fitted with a 20 ft, ¼ in, 10% 1,2,3-Tris(2-cyanoethoxy)propane on 45/60 Gas–Chrom R column, maintained at 120°. A test mixture of authentic alcohols was separated and analyzed with good accuracy (within 1% of actual composition for each alcohol).

† As indicated, temp control of these reactions was difficult. Controls suggest that the reaction of CDM with perchloric acid occurred at an average temperature of −40°. The other aqueous reagents decomposed CDM more slowly. These reactions occurred near 0°.

the ethereal extract was washed with 1N HCl, 10% $NaHCO_3$aq, and water. The washed extract was dried over $CaSO_4$, and stripped of solvent to afford a colourless oil. The oil was purified by VPC at 158° on a 16 ft, $\frac{3}{8}$ in, 15% carbowax 20M on 70/80 Analcrom ABS column. IR: 5·82 μ (neat, carbonyl). NMR: 8·13–7·79, 7·53–7·04, M (aromatic); 4·05, D, J = 6·5 c/s. (—CH_2 –O); 1·52–0·95, M (cyclopropylmethine); 0·76–0·22, M (cyclopropyl). (Found: C, 75·27; H, 6·86. Calc. for $C_{11}H_{12}O_2$: C, 74·97; H, 6·86%.) VPC on the TCEP column* at 180° indicated that the final product contained 4·8% of cyclobutylbenzoate.

Cyclobutylbenzoate. This ester was prepared from cyclobutanol† in a manner analogous to that used in preparation of cyclopropylcarbinyl benzoate. The product was purified by VPC on the preparative carbowax column at 150°. IR: 5·81 μ (neat, carbonyl). NMR: 8·14–7·87, 7·57–7·22, M (aromatic); 5·19. Quintet, J = 7 c/s. (cyclobutyl methine); 2·68–1·50, M (cyclobutyl). (Found: C, 74·60; H, 6·87. Calc. for $C_{11}H_{12}O_2$: C, 74·97; H, 6·86%.) VPC on the TCEP column* at 180° indicated that the final product contained 1·7% allylcarbinyl benzoate and 2·5% cyclopropylcarbinyl benzoate.

Allylcarbinylbenzoate. This ester was prepared from allylcarbinol (Aldrich) in a manner analogous to that used for the other esters. After isolation by VPC on the carbowax column at 150°, analysis on the TCEP* column at 180° showed it to be homogeneous. IR: 5·84 μ (neat, carbonyl). NMR: 8·22–7·77, 7·66–7·11, M (aromatic); 6·25–5·54, M (vinyl); 5·36–4·91, M (=CH_2); 4·32, T, J = 7 c/s. (– CH_2 O); 2·46, (crude) Q, J = 6·5 c/s. (allylic methylene). (Found: C, 74·80, H, 6·57. Calc. for $C_{11}H_{12}O_2$: C, 74·97; H, 6·86%.)

Reactions of cyclopropylmethyldiazotate, I. The diazotate, I, was prepared in the standard way.[15] To a slurry of 2·6 g (0·023 mole) of potassium-t-butoxide in 25 ml of dry ether, stirred at –30° under a N_2 atmosphere, was added 1·98 g (0·012 mole) N-cyclopropylmethyl-N-nitrosourethan in 5 ml ether. After 20 min, no gas evolution had been observed. The diazotate was used *in situ* in subsequent reactions at –40°. 5 Ml of water was injected via a septum. Immediate gas evolution, 80–100% of the theoretical quantity, was observed. The reaction mixture was saturated with K_2CO_3 and extracted with ether. The ether extracts were dried over K_2CO_3, and solvent was carefully distilled. The residue was analyzed on the TCEP column.* The product consisted of a dialkylcarbonate mixture, which has been described previously[15] (in > 90% yield), as well as 30–40% of the expected C_4 alcohol mixture with the distribution recorded in Table 1 (cases 6 and 7). It was not possible to analyze for allylcarbinol directly, since the carbonates had identical retention times. However quantitative benzoylation of the product mixture, followed by VPC analysis of the resulting esters (see above) indicated the presence of no more than 6% of allylcarbinylbenzoate in the ester mixture.

Various control experiments concerning I have been described above. D_2O decompositions of I were carried out as described for water decompositions. The isolated (VPC) alcohols were analyzed by NMR for C–D content (see above).

Diazotate, I, was prepared as described above and 5·6 g (0·046 mole) of benzoic acid in 25 ml ether was rapidly injected through a septum. Gas evolution was essentially instantaneous and quantitative. The reaction mixture was filtered through a sintered glass funnel, washed several times with 10% $NaHCO_3$aq, dried over Na_2SO_4, and stripped of solvent. VPC analyses for C_4 alcohols and their related benzoate esters were carried out as described above. The alcohol distribution is described in the Results Section, and the ester distributions appear in Table 2 (case 5).

Diazotate, I, was prepared as described above and at –50°, 3·23 g (0·023 mole) benzoyl chloride in 5 ml ether was added. No gas evolution was observed, though the reaction mixture took on a deep yellow colour. The temperature was allowed to rise to –20°, at which point gas evolution was observed. At –5°, this evolution was rapid. After ca. 40 min, the reaction mixture was recooled to –50°. (The addition of 5 ml of water gave no additional gas evolution, indicating that all of the diazotate had reacted.) The reaction mixture was filtered, washed with water, dried over sodium sulfate, and stripped of solvent. A yellow oil remained, which, on standing, seemed to slowly evolve gas. VPC analysis of this oil for C_4 benzoates was carried out as described above. The overall benzoate yield was 33%, and the ester distribution appears in Table 2 (case 6).

When the diazotate was reacted with benzoyl chloride at –10°, gas evolution was essentially instantaneous. The product analysis agreed well with the previous experiment. The presence of N-cyclopropylmethyl-N-nitrosobenzamide was demonstrated by the appearance of its characteristic methylene absorption (see below) in the NMR of the product mixture. It was estimated that it had been formed in 10% yield.

N-cyclopropylmethyl-N-nitrosobenzamide. N-cyclopropylmethylbenzamide was prepared from cyclo-

* See footnote (*) on page 2892.

† Prepared in turn from cyclopropylcarbinol, see Reference 22.

propylcarbinylamine and benzoyl chloride in pyridine.[33] A sample purified by sublimation had m.p. 72–74° (lit.,[33] 72·5–74·5°). IR: 1625 cm^{-1} (Nujol, carbonyl). NMR: 7·93–7·50, M superimposed on broad M (aromatic and N—H); 7·40–7·00, M (aromatic); 3·18, *T*, *J* = 6 c/s. (CH_2—N); 1·27 0·75. M (cyclopropyl methine); 0·60–0·10, M (cyclopropyl).

A 50 ml 3-neck flask, equipped with a magnetic stirrer, thermometer, and septum inlet, was charged with 0·85 g (0·005 mole) N-cyclopropylbenzamide, 1·26 g (0·015 mole) $NaHCO_3$, and 13 ml ether. The reaction mixture, under N_2 atmosphere, was cooled to −30°, and a soln of 0·69 g (0·0075 mole) nitrogen tetroxide in 17 ml ether was added in three portions. After stirring for 1 hr at −30°, the reaction mixture was poured into 20 ml 10% $NaHCO_3$ aq (at 0°). Another 20 ml ether was added. The ethereal phase was washed again with bicarbonate soln, then with water, and dried over Na_2SO_4. Solvent was removed under reduced press affording a quantitative yield of the desired product, N-cyclopropylmethyl-N-nitrosobenzamide. IR: 1715 cm^{-1} (neat, carbonyl). NMR: 7·83–7·23, M (aromatic); 3·74, D, *J* = 7 c/s. ($-CH_2$ N); 1·63–0·71, M (cyclopropyl methine); 0·59–0·19, M (cyclopropyl). Compared to the precursor amide, the methylene group of this nitrosoamide has been deshielded by 0·56 ppm. This observation parallels those made in the urethan-nitrosourethan series[31] and serves as good evidence for the structure.

A soln of 0·41 g (0·002 mole) of the N-cyclopropyl-N-nitrosobenzamide in 20 ml ether was stirred at room temp for 7 hr. The evolved gases were passed through a H_2SO_4 scrubber and collected in a gas buret. After apparent evolution of 46·8 ml (96%) of gas, the reaction mixture was stripped of solvent and submitted to VPC on the TCEP column at 160°. The expected C_4 benzoates had been formed in 57% yield with the distribution reported in Table 2 (case 7).

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