

The ester acid chloride was treated with dimethylcadmium to form the methyl ketone,<sup>13</sup> and this was cyclized with potassium *t*-butoxide to produce 4,4-dimethylcyclohexan-1,3-dione,<sup>13</sup> mp 104.5–106° (lit.<sup>13</sup> 106°).

This dione was produced by an alternate path patterned after a method used to prepare 6-pentacyclohexane-1,3-dione.<sup>17</sup> A suspension of sodium ethoxide in xylene was prepared from 17.4 g of ethanol, 6.90 g of sodium, and 200 ml of xylene. To this suspension was added 40 g of ethyl acrylate. While maintaining the temperature at 4°, 13.0 g of 3-methyl-2-butanone was added over a period of 2 hr. After 30 min, the temperature was allowed to rise to 30°, and it was held there until heat evolution subsided. After a further 20 hr at 25°, 100 ml of water was added and the mixture acidified with acetic acid. Ether was added and the ether extract washed with water. The ether extracts from three separate runs were combined, and the solvent was evaporated. Recrystallization of the crude solid from ethyl acetate gave 24.3 g (37%), mp 105–107°. The infrared and nmr spectra were identical with 4,4-dimethylcyclohexane-1,3-dione prepared by the first method, and a mixture melting point showed no depression.

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4,4-Dimethylcyclohexane-1,3-dione was converted to the mono-isobutyl enol ether with isobutyl alcohol and *p*-toluenesulfonic acid as catalyst,<sup>13</sup> yield 66%. Addition of methylmagnesium iodide in ether produced 3,4,4-trimethyl-2-cyclohexen-1-one<sup>13</sup> in 24% yield.

This ketone was treated with methyl lithium in ether. The crude product was a mixture of about 75% 1,3,4,4-tetramethyl-2-cyclohexen-1-ol and 25% of the two dienes formed by dehydration. These percentages were based on a reasonably satisfactory analysis of the nmr spectrum.<sup>18</sup> However, what is of importance is that addition of the mixture to sulfuric acid produced only cation V.

**Acknowledgment.** Acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for partial support of this research. Also acknowledged is support from the National Science Foundation, particularly for the purchase of a Varian A-60 pmr instrument.

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## Rearrangement Accompanying the Photolysis of Diazoacyl Esters<sup>1</sup>

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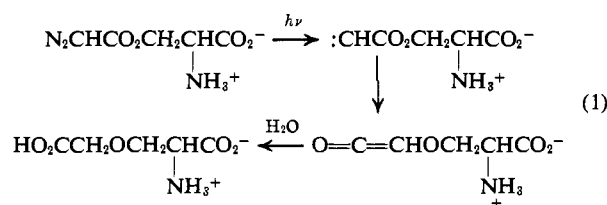
Contribution from the James B. Conant Laboratories of Harvard University, Cambridge, Massachusetts 02139. Received January 30, 1968

**Abstract:** Ethyl diazoacetate, phenyl diazoacetate, and *N*-methyl diazoacetamide were photolyzed in aqueous or methanolic solution and the products identified. In all cases, two major products were formed: one by the insertion of the expected carbene into water or the OH bond of methanol, the other by a rearrangement analogous to the photochemical Wolff rearrangement of diazo ketones. A minor product (ethyl  $\beta$ -hydroxypropionate) from the photolysis of ethyl diazoacetate in methanol is formed by C–H insertion. Methyl phenoxycetate, formed by photochemical rearrangement of phenyl diazoacetate, undergoes further photochemical reaction to yield methyl esters of *o*- and *p*-hydroxyphenylacetic acids.

Diazo compounds may be used to probe the nature of the active sites of enzymes. These compounds (in the presence<sup>3–5</sup> or absence<sup>5–7</sup> of cupric ion) react stoichiometrically with proteins, presumably at a carboxyl group. In a second type of investigation, illustrated by the preparation of diazoacetyl chymotrypsin,<sup>8–10</sup> a diazo ester is attached at the active site of the enzyme and then subsequently the diazo group is forced to react with neighboring amino acid residues. In particular, photolysis of diazoacetyl chymotrypsin presumably generates a carbene that reacts by a mo-

lecular rearrangement analogous to the  $\delta$  rearrangement of diazo ketones, by insertion into water, or by insertion into amino acid residues, where a histidine and a tyrosine residue have so far been identified as objects of attack.

The rearrangement encountered in these investigations was also illustrated<sup>10</sup> with azaserine, which reacts in part as shown in eq 1.



The photolysis of diazo esters extends the range of the Wolff rearrangement;<sup>11,12</sup> before these examples, no rearrangement of a diazo ester was known, although a rearrangement of an alkoxy group in a diazo acetal<sup>13</sup> was discovered independently and published simultaneously with our preliminary<sup>9</sup> announcement. Re-

(1) This research was supported by Grant GM-04712 of the Institute of General Medical Sciences of the National Institutes of Health.

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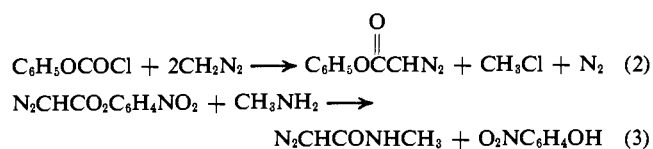
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cently DoMinh, Gunning, and Strausz<sup>14</sup> have described the rearrangement of the carbyne radical,  $:\dot{\text{C}}\text{C}-\text{O}_2\text{C}_2\text{H}_5$ , and (in a footnote) announced the forthcoming publication of a study of the rearrangement of carbethoxymethylene. The present article reports the rearrangement on photolysis of ethyl diazoacetate (to yield the carbethoxymethylene treated by DoMinh, *et al.*) and also the rearrangement on photolysis of phenyl diazoacetate and N-methyldiazoacetamide, and thus examines the migration aptitude of an alkoxy group, an aryloxy group, and an alkylamino group. These compounds were chosen both for their intrinsic chemical interest and because the results will be biochemically useful. The value of a diazo compound in labeling a protein is generally limited by rearrangement, which effectively "wastes" carbene that otherwise could react with and mark groups near the active site. However, cases may arise where the nucleophilic site of a protein can usefully be marked by the rearrangement. In either event, this study of the tendency toward rearrangement of these compounds provides background information for enzymic studies.

Phenyl diazoacetate is conveniently prepared from phenyl chloroformate and diazomethane, by an extension of the synthesis previously published.<sup>10</sup> N-Methyldiazoacetamide may be prepared from *p*-nitrophenyl diazoacetate and aqueous methylamine.



## Experimental Section

**Materials.** The nmr spectrum of ethyl diazoacetate (Aldrich) showed an unknown impurity. After 0.5 g of the ester had been eluted with ligroin from 80 g of Woelm grade V alumina, the resulting ester (in carbon tetrachloride) showed only the appropriate nmr peaks for the ethyl group and the single  $\alpha$  proton.

**Phenyl diazoacetate** was synthesized by the addition of 4.5 g of phenyl chloroformate (Eastman) in 100 ml of ether at 0° to a vigorously stirred ether solution of excess diazomethane at 0°. After 12 hr at 0°, the excess diazomethane was removed by bubbling dry nitrogen through the solution at 0° for 2 hr, and the ether was removed *in vacuo*. The remaining liquid was dissolved in ligroin and chromatographed on 80 g of Woelm grade V alumina. The compound was eluted with ligroin and the solvent removed by rotary evaporation. The residue was twice more chromatographed; the last time it was eluted from grade III alumina with benzene-ligroin (1:4). After evaporation, the resulting clear yellow liquid was distilled at 35–40° (0.01 mm). It showed major ir peaks at 3.19 (w), 4.69, 5.84, 6.29, 6.70, 7.31, 7.45, 8.36, and 8.71  $\mu$ . *Anal.* Calcd for  $\text{C}_8\text{H}_8\text{N}_2\text{O}_2$ : C, 59.26; H, 3.73; N, 17.28. Found: C, 59.86; H, 3.80; N, 16.98. The uv spectrum shows a single peak,  $\lambda_{\text{max}}$  251  $m\mu$  ( $\epsilon$  16,000). The mass spectrum shows the parent peak at 162 mass units, and peaks at 134 (loss of  $\text{N}_2$ ) and 106 (loss of CO from 134); the base peak is that of phenol. The nmr spectrum is consistent with the assigned structure.

**N-Methyldiazoacetamide.** *p*-Nitrophenyl diazoacetate<sup>10</sup> (500 mg) was suspended in 5 ml of 40% aqueous methylamine solution at room temperature. After an hour, the mixture was evaporated to dryness and the residue taken up in hot ethyl acetate. The supernatant from the cooled suspension was chromatographed on Woelm grade V alumina with ethyl acetate–benzene (1:4). The yellow fraction was rechromatographed on 35 g of grade V alumina with ethyl acetate–benzene (1:10) as eluent. Two fractions were obtained. The first (mp 127°) has not been further investigated. The second fraction (N-methyldiazoacetamide) after recrystalliza-

tion from benzene–ligroin, melted at 89.0–89.5°, yield 100 mg. The compound in KBr shows strong ir peaks at 3.00, 3.21, 4.75, 6.21, 6.36, 7.31, 7.99, 8.65, 9.60, and 10.53  $\mu$ . Its nmr spectrum in  $\text{D}_2\text{O}$  showed only a singlet at  $\delta$  2.68 and a water peak at  $\delta$  4.70; the single methine proton exchanges with solvent. The mass spectrum of the diazoamide gave the parent peak (mass 99) as the base peak, with strong peaks at 71 (loss of  $\text{N}_2$ ) and at 69 (loss of  $\text{CH}_2\text{NH}$ ). The ultraviolet spectrum shows only one peak at 258  $m\mu$ . *Anal.* Calcd for  $\text{C}_8\text{H}_8\text{N}_2\text{O}$ : C, 36.36; H, 5.08; N, 42.42. Found: C, 36.70; H, 5.01; N, 42.08.

When 2,4-dinitrophenyl diazoacetate was allowed to react with aqueous methylamine under the same conditions, only N-methyl-2,4-dinitroaniline was isolated.

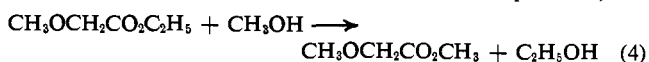
**Compounds Needed for Identification.** Ethyl methoxyacetate, prepared by esterification of Eastman methoxyacetic acid with alcohol and sulfuric acid, gave an nmr spectrum in deuteriochloroform with a triplet (3 H) centered at  $\delta$  1.30,  $J = 7$  cps, a singlet (3 H) at  $\delta$  3.46, a singlet (2 H) at  $\delta$  4.03, and an overlapping quartet centered at  $\delta$  4.21,  $J = 7$  cps, in accordance with its structure. Phenyl methoxyacetate was made *via* the acid chloride (prepared from Eastman's methoxyacetic acid and thionyl chloride). Phenol (10.2 g) and pyridine (14 g) were added in portions to a solution of the acid chloride (15.8 g) in benzene (30 ml). After the mixture had been stirred for 2 hr at 30°, it was quenched with water and extracted with benzene. The benzene solution was washed with acid, bicarbonate solution, and brine and dried with magnesium sulfate. After the solvent was removed, the residue distilled at 99–101° (0.6–0.7 mm). *Anal.* Calcd for  $\text{C}_9\text{H}_{10}\text{O}_2$ : C, 65.05; H, 6.07. Found: C, 65.16; H, 6.20. The nmr spectrum in deuteriochloroform showed a singlet (3 H) at  $\delta$  3.50, a singlet (2 H) at  $\delta$  4.25, and a multiplet (5 H) centered at  $\delta$  7.25.

N-Methylglycolamide was prepared according to Biltz<sup>15</sup> and melted at 65–67° (lit.<sup>15</sup> sinters at 62°, melts at 72°). Methyl phenoxyacetate<sup>16</sup> boiled at 69–70° (0.15 mm); its nmr spectrum in deuteriochloroform showed a singlet at  $\delta$  3.79 (3 H), a singlet at  $\delta$  4.61 (2 H), and a multiplet (5 H) centered at  $\delta$  7.1. Methyl methoxyacetate<sup>17</sup> boiled at 131° (1 atm), methyl *p*-hydroxyphenylacetate<sup>18</sup> boiled at 117–119° (0.25 mm), and methyl *o*-hydroxyphenylacetate<sup>19</sup> melted at 71.5–72.0°. Ethyl  $\beta$ -hydroxypropionate was prepared according to Gresham, *et al.*,<sup>20</sup> and boiled at 68–69° (5 mm) (lit.<sup>20</sup> 75° (8 mm)). Its nmr spectrum corresponds to that expected for this structure. Other chemicals were the best commercial grades. The Merck tetradeuteriomethanol contained a small nmr active impurity that, however, did not interfere with this investigation.

**Methods.** Infrared spectra were determined with a Perkin-Elmer Infracord and nmr spectra with a Varian A-60, using tetramethylsilane as (internal or external) standard; ultraviolet spectra were measured with a Cary 15 double-beam spectrophotometer.

Photolyses were carried out in a Rayonet photochemical reactor, equipped with RPR 2537 lamps. Samples were placed in quartz tubes and surrounded by an outer quartz tube; cooling water was circulated through the annular space between them in order to maintain a temperature of about 12°. On occasion, photolyses were carried out directly in quartz nmr tubes (Nuclear Magnetic Resonance Specialties, Inc.). The photolyses of the diazo compounds at 2537 Å in 25–80 ml of solution required about 15–30 sec/mg. The photolysis in quartz nmr tubes required about 200 sec/mg. The photolysis of methyl phenoxyacetate required a similar amount of time.

Samples from the photolysis of ethyl diazoacetate were prepared for vpc analysis either (1) by careful low-temperature evaporation of the solvent, to minimize transesterification, or (2) by refluxing the photolysis solution (25 ml) with added sulfuric acid (50  $\mu$ l) to effect complete transesterification. In the latter experiment, the



acid was neutralized with solid dipotassium hydrogen phosphate, and the reaction mixture flash-distilled (80° (0.1 mm)) into a cold trap. The contents of the trap were fractionated to remove most of the methanol, and the last 4 ml was used directly for vpc analysis.

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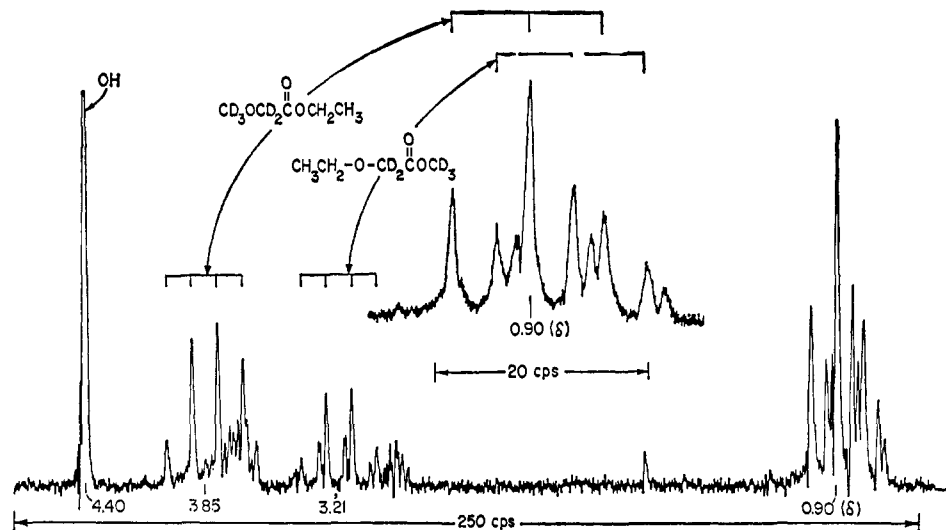


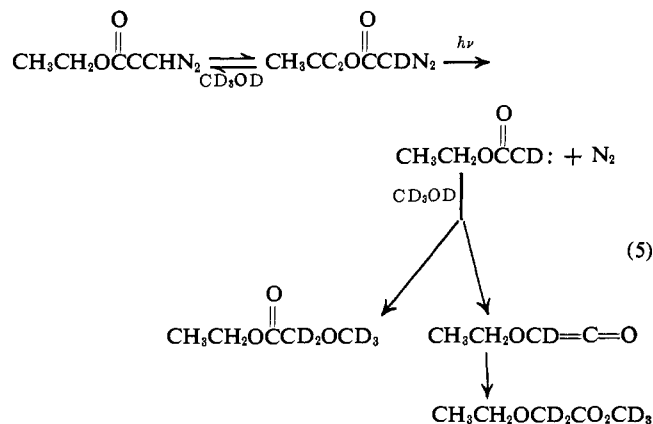
Figure 1. The nmr spectrum of the products of the photolysis of ethyl diazoacetate in tetradeuteriomethanol. The signals from the methyl groups of the various ethyl residues appear around  $\delta$  0.90, and these signals are shown in an expanded scale in the inset. From lower to higher field in this group of signals, the first, fourth, and seventh peaks are those of the  $\text{CH}_3$  in the ethyl group of ethyl methoxyacetate, while the second, fifth, and eighth peaks are those of the  $\text{CH}_3$  in the ethyl group of methyl ethoxyacetate. The third, sixth, and ninth peaks arise from the  $\text{CH}_3$  in ethanol. (The trace of ethyl  $\beta$ -hydroxypropionate that is formed is not clearly visible in this spectrum; the peaks appear only as minor shoulders at the base of the larger signals.) The methylene region is complex because the methine proton in ethyl diazoacetate exchanges but does not completely exchange with deuterium during photolysis. The major quartet at  $\delta$  3.85 is that from the  $\text{CH}_2$  of the ethyl group of ethyl methoxyacetate, while the major quartet at  $\delta$  3.21 is that from the  $\text{CH}_2$  of the ethyl group of methyl ethoxyacetate. The "hash" upfield from the later quartet is present in the deuteriomethanol used as solvent.

The samples prepared according to (1) were subjected to vpc analysis on a 20 ft  $\times$  1/8 in. column of 15%  $\beta,\beta'$ -oxydipropionitrile on Chromosorb P (column temperature 90°, injection temperature 240°, flow rate 25 cc/min, flame ionization detector). This column separated methyl ethoxyacetate, ethyl methoxyacetate, and methyl methoxyacetate. A less selective column with respect to the esters (*i.e.*, a 6 ft  $\times$  1/8 in. column of 10% UCW98 silicone rubber) operated on a temperature gradient revealed a few per cent of a compound of longer retention time. The retention time of this component under three different conditions corresponded to that of ethyl  $\beta$ -hydroxypropionate. These conditions, in addition to those mentioned above, involved a 12 ft  $\times$  1/8 in. column of 20% Carbowax 20 M on Chromosorb P at 175°, and a 5 ft  $\times$  1/4 in. column of didecyl phthalate on Fluoropak at 117°. With this latter column, a sufficient quantity of the new component was collected to permit the determination of its infrared spectrum as a liquid film. This spectrum was identical in all respects with that of ethyl  $\beta$ -hydroxypropionate.

The products from the photolysis of phenyl diazoacetate were separated on a 6 ft  $\times$  1/8 in. column of 10% UCW98 (silicone rubber) with a temperature gradient from 115 to 200°. Either a Varian Aerograph A-100 or a Hewlett-Packard 5754 A vpc was used for analysis. All elementary analyses were conducted by Galbraith Laboratories.

## Results

The photolysis of ethyl diazoacetate was conducted in deuteriomethanol as solvent (concentrations 1:7). The expected chemistry, shown in eq 5, accounts for the major components found. The methine hydrogen atom of the diazo esters exchanges with deuteriomethanol at a rate exceeding that of photolysis, as demonstrated by nmr analysis. The nmr spectrum of the reaction mixture is shown in Figure 1. A comparison of the peaks with those of ethyl methoxyacetate and of methyl ethoxyacetate shows that all the major peaks in the spectrum of the product can be accounted for. Of course, with deuteriomethanol as solvent, the penta-deuterio reaction products have somewhat different nmr spectra from those of their hydrogen analogs, but the positions of the methyl and the methylene groups of the ethyl groups are characteristic for the two expected



products; addition of ethyl methoxyacetate to a portion of the reaction mixture shows an increase in the appropriate ethyl bands without introduction of any new ones, and, similarly, addition of methyl ethoxyacetate enhances the bands appropriate to that compound. The peaks overlap too much to permit accurate integration to give a quantitative analysis of the mixture; an approximate analysis was obtained by integrating one of the peaks of the methyl triplet in ethyl methoxyacetate (see inset, Figure 1). In a control experiment 50  $\mu\text{l}$  of ethyl diazoacetate dissolved in 500  $\mu\text{l}$  of deuteriomethanol showed no change in nmr spectrum after 120 min in the dark. About 10% of a third component can be seen in the nmr spectrum of the ethyl groups. The peak positions are characteristic of ethanol.

The products of photolysis were separated by vpc analysis on a long (20 ft) column, and the two major products, methyl ethoxyacetate and ethyl methoxyacetate, were identified by their retention times. These results were confirmed by carrying out an ester exchange with methanol by acidifying the photolysis mixture with sulfuric acid and heating it. The products were identi-

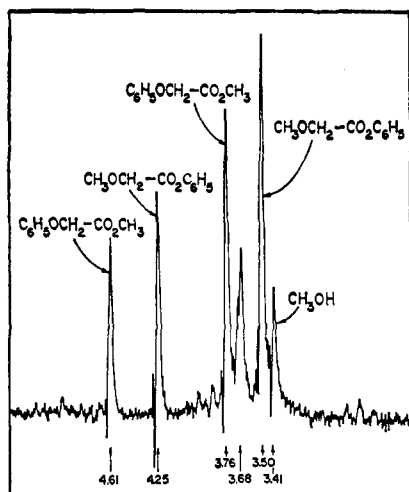
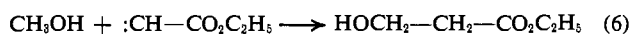


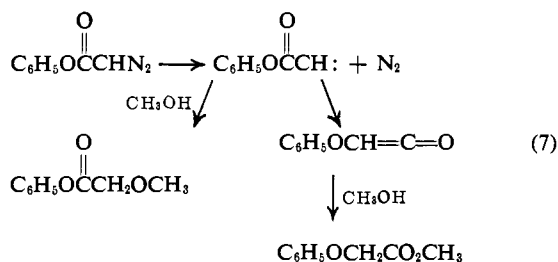
Figure 2. The nmr spectrum in deuteriochloroform of the residue from the evaporation of the solvent from the products of the photolysis in methanol of phenyl diazoacetate. The positions of the peaks are measured relative to TMS as internal standard. The peak at  $\delta$  3.68 is shown in an expanded scale in Figure 4 and explained in the text.

fied by their retention times as methyl methoxyacetate and methyl ethoxyacetate. The percentage of rearrangement from the photolysis of ethyl diazoacetate proved (by vpc analysis) approximately the same in methanol as in tetradeuteriomethanol. Any isotope effect in the reaction (although perhaps real) must then be small, and its effects hidden by our moderate analytical uncertainty.

Most interesting, perhaps, is the identification by vpc, nmr, and ir analysis of ethyl  $\beta$ -hydroxypropionate as a minor product of the photolysis. This compound presumably arises by insertion of carbethoxycarbene into one of the C-H bonds of methanol.



The photolysis of phenyl diazoacetate was conducted by dissolving 200 mg of the diazo ester in 20 ml of methanol and irradiating the solution.



The solution was photolyzed for 60 min and the methanol removed by rotary evaporation. The nmr spectrum of the resulting oil in deuteriochloroform is shown in Figure 2. Comparison with the spectra of phenyl methoxyacetate and of methyl phenoxyacetate confirms that these products are present, but, in addition to the nmr peaks for these products, an additional peak at  $\delta$  3.68 must be accounted for. The detailed discussion of this peak is given below; first the identification of the major products is described.

When a concentrated solution from the photolysis was subjected to vpc analysis, three peaks appeared. These could be separated and collected in sufficient quantity so that their nmr spectra could be individually

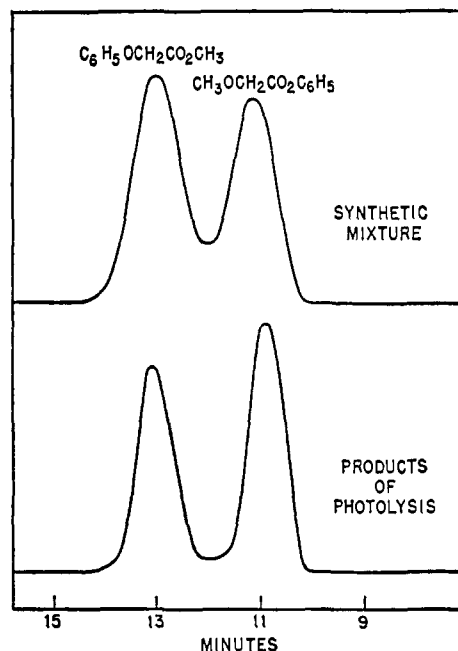
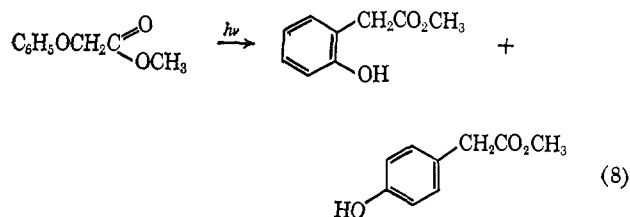


Figure 3. A vpc trace of the ester products from the photolysis of phenyl diazoacetate in methanol. (The column was 5 ft  $\times$  1/4 in. of 20% Carbowax 20M on Chromosorb W,  $T = 108^\circ$ .) The upper trace is that of a synthetic mixture of the two esters.

determined, and they were then identified as phenyl methoxyacetate, methyl phenoxyacetate, and a little phenol. A vpc run, showing only the two esters, is given in Figure 3, along with that of a synthetic mixture. The products then have been identified both by their vpc and nmr spectra.

In a control experiment, a solution of  $9 \times 10^{-5} M$  phenyl diazoacetate was allowed to stand at room temperature for 80 min in the dark; no change in the uv spectrum of this solution could be detected.

When the spectral region around  $\delta$  3.68 was expanded (Figure 4), it became apparent that this signal represented two compounds, rather than one. Further investigation has shown that these peaks arise from the further photolysis of methyl phenoxyacetate, according to the equation



After the photolysis of methyl phenoxyacetate in methanol, the solvent was carefully removed by fractional distillation, and the products were separated from unchanged ester by extraction of an ether solution of the residue with 1  $M$  sodium hydroxide solution. Acidification of the alkali solution yielded a brown oil which was fractionated by sublimation and carbon tetrachloride solubility to yield methyl *o*-hydroxyphenylacetate (identified by comparison of its ir and nmr spectra and its melting point with those of an authentic sample) and a mixture of *o*- and *p*-hydroxyphenylacetic acids (identified by comparisons of the ir and nmr spectra with those of authentic samples). Though its

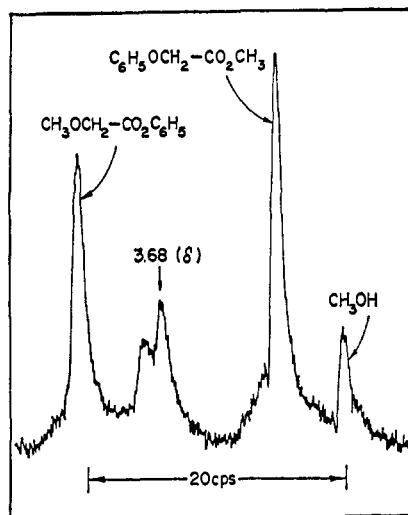
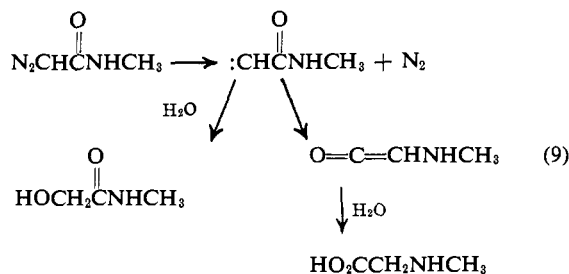


Figure 4. Scale expansion (100 cycles full scale) of the region around  $\delta$  3.68 in the nmr spectrum of the products of photolysis of phenyl diazoacetate in methanol (cf. Figure 2). The lower of the two peaks centered at  $\delta$  3.68 is that of the methyl group of methyl *o*-hydroxyphenylacetate, while the higher of these two peaks is that from superposition of the signal from the methyl group of methyl *p*-hydroxyphenylacetate, and that of the methylene group of the *ortho* isomer. The signal from the methylene group of the *para* isomer appears indistinctly as a shoulder on the methyl peak of methyl phenoxyacetate.

presence was indicated in the spectra of the carbon tetrachloride soluble material, methyl *p*-hydroxyphenylacetate was not isolated in pure form. The nmr spectrum of the photolysis mixture was compared with those of authentic samples of the methyl esters of *o*- and *p*-hydroxyphenylacetic acids. Authentic samples added to the photolysis mixture enhanced one or the other of the two peaks near  $\delta$  3.68, without introducing any new peaks.

The photolysis of *N*-methyl diazoacetamide was conducted in either  $H_2O$  or  $D_2O$  in 0.01 *M* phosphate buffer, pH 6.40. For example, a solution of 11.8 mg of the diazoacetamide in 25 ml of buffer lost 99.5% of its optical density on photolysis for 7 min. When the photolysis of *N*-methyl diazoacetamide was conducted in water, rotary evaporation gave solids that could be redissolved in  $D_2O$  without exchange of carbon-hydrogen bonds. The resulting spectrum (Figure 5) corresponds to that of a mixture of sarcosine and *N*-methylglycolamide in  $D_2O$ . The expected chemistry is shown in eq 9. When the photolyses were conducted in  $D_2O$ ,



the products contained hydrogen only in the methyl groups; the methylene groups were substituted by deuterium.

**Products of Photolysis.** The yields of rearranged products produced in the photolysis experiments are shown in Table I.

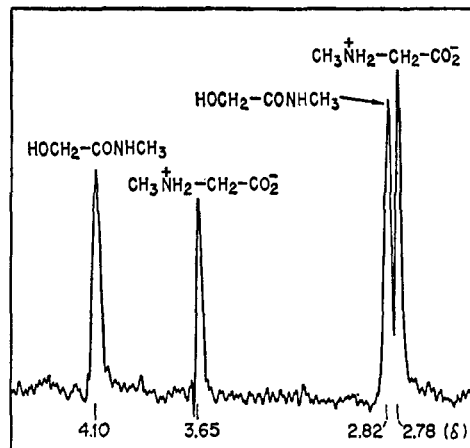


Figure 5. The nmr spectrum in  $D_2O$  of the products of the photolysis in  $H_2O$  of *N*-methyl diazoacetamide.

Table I. Rearrangement in the Photolysis of Diazo Esters and a Diazo amide

Compound	Method	Approx % rearr
Ethyl diazoacetate	Nmr, vpc	20-25
Phenyl diazoacetate	Nmr	45-60
<i>N</i> -Methyl diazoacetamide	Nmr	30

The yields of rearranged and unrearranged esters in the photolysis of phenyl diazoacetate have been estimated by adding the yield of the methyl esters of *o*- and *p*-hydroxyphenylacetic acids to that of methyl phenoxyacetate, since these products arise exclusively from photolysis of the latter. The minor products of photolysis are considered in the discussion.

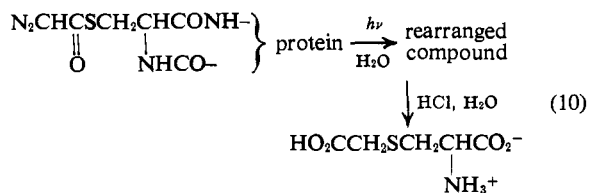
## Discussion

The data in this paper show that two diazo esters and a diazoamide undergo 20-60% rearrangement on photolysis. The data of Strausz, DoMinh, and Gunning<sup>21</sup> for the photolysis of ethyl diazoacetate in isopropyl alcohol as solvent are similar to ours for photolysis in methanol. They report 29% rearrangement, 25% OH insertion, 12% ester exchange, and 9% C-H insertion. The percentage rearrangement that we have found is, as a first approximation, rather similar for all three starting materials, although there is a slight preference for rearrangement for the phenyl ester as compared to that of the ethyl ester and amide. On the other hand, the one example available for photolysis of a diazo thioester showed essentially complete rearrangement to sulfur. Scott<sup>22</sup> prepared the diazoacetyl derivative of glyceraldehyde-3-phosphate dehydrogenase, following the directions for the preparation of the acetyl derivative of Park, *et al.*<sup>23</sup> Photolysis of this enzyme yielded a product which, on hydrolysis, gave only carboxymethylcysteine, identified by column chromatography.

(21) O. P. Strausz, T. DoMinh, and H. E. Gunning, *J. Am. Chem. Soc.*, **90**, 1660 (1968). The authors gratefully acknowledge Professor Gunning's cooperation in an exchange of manuscripts that allowed us to see his results prior to their publication.

(22) L. J. Scott, unpublished results.

(23) E. L. Taylor, B. P. Meriwether, and J. H. Park, *J. Biol. Chem.*, **238**, 734 (1963).



Similar rearrangement to a neighboring sulfur atom was reported by Robson and Shechter<sup>24</sup> in the reaction (presumably by way of a diazo compound and the corresponding carbene) of 2-ethylmercaptoacetophenone *p*-tosylhydrazone.

Migration to sulfur, in preference to insertion into water, may well be expected from carbenes. However, it was also anticipated that the migration would be greater for an amide than for an ethyl ester and greater for an ethyl ester than for a phenyl ester, on the basis of qualitative ideas of the relative availability of electrons on these atoms. Such was not the fact. We have not yet understood the reasons why the percentage of rearrangement in the compounds here studied proved essentially independent of structure, and the results may be, in part, an artifact arising from differences in experimental conditions for the various photolyses. Prior work with ethyl trifluoroacetyldiazoacetate had yielded the products of attack on solvent, rather than those of rearrangement,<sup>25</sup> and these results had been generalized to suggest that alkoxy groups do not migrate in Wolff-type rearrangements of diazo esters.<sup>26</sup> It now appears probable that the particular choice of diazo ester con-

(24) J. H. Robson and H. Shechter, *J. Am. Chem. Soc.*, **89**, 7112 (1967).

(25) F. Weygand, H. Dworschak, K. Koch, and St. Konstas, *Angew. Chem.*, **73**, 409 (1961).

(26) P. A. S. Smith in "Molecular Rearrangements," P. de Mayo, Ed., Interscience Publishers New York, N. Y., 1963, p 560.

trolled the results obtained. Many experiments have been conducted on the photolysis of ethyl diazoacetate<sup>27</sup> in nonpolar solvents, but in these experiments the products of insertion into C-H bonds were deliberately sought, and the ketene (if indeed it is formed under the experimental conditions of these reactions) would not easily have been found. Insertion into the C-H bond of methanol has here been detected as a minor product in the photolysis of ethyl diazoacetate in this polar solvent. The result is significant, since it encourages us to continue the search for C-H insertion products in the photolysis of diazoacetylchymotrypsin and other diazoacetylated enzymes. Such insertions, if found, would provide a welcome, and at present unique, means of marking the hydrophobic residues near the active sites of enzymes.

It must then be concluded that the analog of a photochemical Wolff rearrangement does indeed occur to a limited extent with diazo esters, but that it is restricted (at least in diazo esters) to compounds that do not carry strongly electronegative groups. Kaplan and Meloy<sup>28</sup> raise the question as to whether the products of the decomposition of diazo ketones are influenced by the conformation of the compounds. The application of their idea to the photochemistry here outlined is not straightforward, but deserves investigation.

The mechanism of the photolysis of methyl phenoxyacetate has not yet been elucidated. But the products formed are analogous to those obtained in low yield in the thermal reaction of acetyl peroxide with phenols,<sup>29</sup> and this fact suggests that the reaction proceeds by a free-radical process.

(27) W. von E. Doering and L. H. Knox, *J. Am. Chem. Soc.*, **78**, 4947 (1956); **83**, 1989 (1961).

(28) F. Kaplan and G. K. Meloy, *ibid.*, **88**, 950 (1966).

(29) F. Wessely and E. Schinzel, *Monatsh.*, **84**, 969 (1953).

## The Decomposition of Peroxy Esters. II. The Photolysis of Esters of Aliphatic Peroxycarboxylic Acids

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**Abstract:** Photolysis of the long-chain aliphatic peroxy esters, *t*-butyl peroxycaprate and *t*-butyl peroxy laurate, in the pure liquid state was carried out at 30° with 2537 Å ultraviolet radiation. The principal products formed were carbon dioxide, capric or lauric acid, *t*-butyl alcohol, methane, and acetone. The quantum yield for each of these products was independent of the intensity of the radiation. The magnitude of the quantum yields for the decomposition of the peroxy esters and the inhibiting effect of oxygen indicate that some induced decomposition takes place in addition to the photochemical decomposition.

The thermal decomposition of aliphatic peroxy esters, RCOOR', where both R and R' are alkyl groups, has been the subject of several investigations.<sup>1</sup>

(1) See, for example: (a) P. D. Bartlett and R. R. Hiatt, *J. Am. Chem. Soc.*, **80**, 1398 (1958); (b) N. A. Milas and A. Golubović, *ibid.*, **80**, 5994 (1958); (c) L. J. Durham, L. Glover, and H. S. Mosher, *ibid.*, **82**, 1508 (1960); (d) R. E. Pincock, *ibid.*, **84**, 312 (1962); (e) M. Trachtman and J. G. Miller, *ibid.*, **84**, 4828 (1962); (f) P. D. Bartlett and H. Minato, *ibid.*, **85**, 1858 (1963); (g) P. D. Bartlett and L. B. Gortler, *ibid.*, **85**, 1864 (1963); (h) J. R. Shelton and H. G. Gilde, *J. Org. Chem.*, **29**, 482 (1964).

The importance of reactions of *t*-butyl peroxy esters, such as *t*-butyl peroxyacetate, with many classes of compounds in the presence of catalytic amounts of copper ions to produce well-defined acyloxy derivatives has been demonstrated.<sup>2</sup> Although Sosnovsky<sup>3</sup> has shown that those peroxy ester reactions are aided by

(2) G. Sosnovsky and S.-O. Lawesson, *Angew. Chem. Intern. Ed. Engl.*, **3**, 269 (1964).

(3) G. Sosnovsky, *J. Org. Chem.*, **28**, 2934 (1963); *Tetrahedron*, **21**, 871 (1965).