Anal. Calcd. for $C_{13}H_{24}O_2$: C, 73.5; H, 11.4; neut. equiv., 212.3. Found: C, 73.6; H, 11.3; neut. equiv., 207.8.

For characterization a sample of the acid was converted to the S-benzylthiuronium salt which was recrystallized from dioxane; m.p. 134–135°.

Anal. Calcd. for $C_{21}H_{34}O_2N_2S$: C, 66.6; H, 9.1; S, 8.5; N, 7.4. Found: C, 66.2; H, 9.0; S, 8.6; N, 7.3.

DL-7-Keto-*cis*-9,10-methyleneoctadecanoic Acid (VII).—The acid chloride of VI was prepared in the usual manner from the acid (12.3 g.), oxalyl chloride (9.2 g.) in benzene (50 ml.) and a trace of pyridine. The benzene was evaporated, the oily acid chloride was dissolved in benzene (50 ml.) and the solution added slowly, with stirring, to an ice-cold suspension of ethyl sodioacetoacetate (prepared in the usual manner from 9.4 g. of freshly distilled ethyl acetoacetate, 1.4 g. of powdered sodium in 100 ml. of benzene). The mixture was refluxed for 10 minutes, with stirring, cooled to room temperature and poured on cracked ice. It was acidified to congo red with aqueous sulfuric acid 1:1 v./v., the organic phase was separated and the aqueous solution extracted with two 100-ml. portions of fresh benzene. The organic extracts were washed with several portions of saturated sodium chloride, dried over sodium sulfate and the benzene was removed *in vacuo*. The oily residue was dissolved in a sodium methoxide solution prepared from methanol (58 ml.) and sodium (1.6 g.) and the mixture was allowed to stand at room temperature for 8 hours. The solution was diluted with water, acidified to congo red with sulfuric acid, and saturated with sodium chloride. The mixture was extracted with three 100-ml. portions of ether, the ethereal extracts were washed with saturated sodium chloride, dried over sodium sulfate and the ether was evaporated. The residual oil (16.4 g.) was dissolved in methanol (100 ml.) and a solution of cupric acetate (5.2 g.) in water (75 ml.) was added. The oily copper chelate which settled to the bottom of the flask was collected by centrifugation, and the supernatant liquid was discarded. The chelate was dissolved in ether and the ethereal solution washed with dilute sulfuric acid until the green color had disappeared. The ether layer was washed with saturated sodium chloride, dried over sodium sulfate, and the ether was evaporated. Distillation of the residue gave crude methyl DL-3-keto-*cis*-5,6-methylenetetradecanoate, b.p. 130–150° at 3 mm., which was employed for further work. The material gave a deep red color with ferric chloride; yield 11.3 g. (72%). The β-ketoester (11.3 g.) was dissolved in methyl *n*-propyl ketone (130 ml.), methyl 5-iodovalerate[18] (10.2 g.) and anhydrous potassium carbonate (19.1 g.) were added and the mixture was refluxed, with stirring, for 16 hours. The cooled suspension was filtered through a layer of Hyflo Filter-cel and the filter cake was washed with ether. The combined filtrate and washings were evaporated to dryness *in vacuo* and the resulting oil (17 g.) was dissolved in a solution of potassium hydroxide (34.0 g.) in methanol (510 ml.) and water (34 ml.). The mixture was kept at 45° for 24 hours when the acid VII was isolated in the usual manner. The acid (9.6 g.) was obtained in the form of an oil which crystallized on standing. Recrystallization first from petroleum ether, then from acetone at −20° gave cream colored plates (4.6 g.) which melted at 30.6–32.0°.

Anal. Calcd. for $C_{19}H_{34}O_3$: C, 73.5; H, 11.0; neut. equiv., 310.5. Found: C, 73.2; H, 10.9; neut. equiv., 308.4.

DL-*cis*-9,10-Methyleneoctadecanoic Acid (Dihydrosterculic Acid) (III).—The keto acid VII (5.7 g.) in ethylene glycol (25 ml.), potassium hydroxide (3.5 g.) and hydrazine hydrate (2.5 ml.) was reduced in the manner described for the preparation of VI. The resulting crude acid (5.5 g.) was recrystallized to constant melting point from petroleum ether and then from acetone at −20°; yield 2.9 g., m.p. 38.6–39.6°. No depression of melting point was obtained when this sample was admixed with dihydrosterculic acid, m.p. 39.0–40.2°.[8] The mother liquors were combined, the solvent evaporated and the residue esterified with diazomethane. Distillation of the ester in a spinning band type column with "Gulf petrowax A" (6.5 g.) as a "chaser" gave 2.2 g. of a fraction boiling at 178–182° at 3 ± 0.2 mm. This was saponified and the ensuing acid was recrystallized from petroleum ether at −20° to yield an additional 1.0 g. of material, m.p. 37.4–38.6°.

Anal. Calcd. for $C_{19}H_{36}O_2$: C, 77.0; H, 12.2; neut. equiv., 296.4. Found: C, 77.0; H, 12.2; neut. equiv., 298.4.

A sample of the acid was converted into the amide which melted at 86.4–87.6° following three recrystallizations from methanol.

Anal. Calcd. for $C_{19}H_{37}ON$: C, 77.2; H, 12.6; N, 4.7. Found: C, 77.0; H, 12.3; N, 5.0.

Dihydrosterculamide.—A sample of dihydrosterculic acid from sterculic acid[8] was converted into the amide; m.p. 86.4–87.6° from methanol. No depression of the melting point was observed when this sample was admixed with the synthetic amide.

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(18) For the preparation of this compound, 5-bromovaleronitrile (Columbia-Organic Chemicals, Inc.) was converted into methyl 5-bromovalerate (b.p. 110–112° at 12 mm., $n^{25}\mathrm{D}$ 1.4761) according to the method of M. W. Cronyn, *J. Org. Chem.*, **14**, 1013 (1949), and the latter was transformed into the iodo compound by refluxing with potassium iodide in acetone. A fraction b.p. 104–111° at 8 mm. was used.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY]

Studies in Organic Peroxides. XXIII. The Use of Paper Chromatography for the Detection and Separation of Organic Peroxides[1,1a]

BY NICHOLAS A. MILAS AND IGOR BELIČ[2]

RECEIVED DECEMBER 17, 1958

The present investigation was undertaken to develop a simple and rapid method for the detection and separation of organic peroxides in very small quantities. A paper chromatographic method was developed which permits the detection and separation of certain organic peroxides in quantities as low as 0.2–0.5 γ. This method has already proved of considerable value (see paper XXIV) in the separation and identification of new organic peroxides.

When simple aliphatic ketones are allowed to react with hydrogen peroxide under various conditions, a mixture of different peroxides is formed at the same time. The complete separation and identification of all possible peroxides has been a very difficult task and, in spite of the extensive work reported in this field,[3-7] progress has been

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(1) Paper XXII, THIS JOURNAL, **80**, 5994 (1958).

(1a) Originally submitted to *Anal. Chem.* Nov. 27, 1957, and subsequently withdrawn for publication with paper XXIV.

(2) Lucidol Research Associate.

(3) R. Criegee, "Herstellung und Umwandlung von Peroxiden" (Houben-Weyl), Methoden der Org. Chem. Bd. VIII (1952).

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(6) N. Brown, M. J. Hartig, M. J. Roedel, A. W. Anderson and C. E. Schweitzer, THIS JOURNAL, **77**, 1756 (1955).

(7) A. Rieche, *Angew. Chem.*, **70**, 251 (1958).

slow because of lack of a suitable method for their separation and identification without appreciable decomposition.

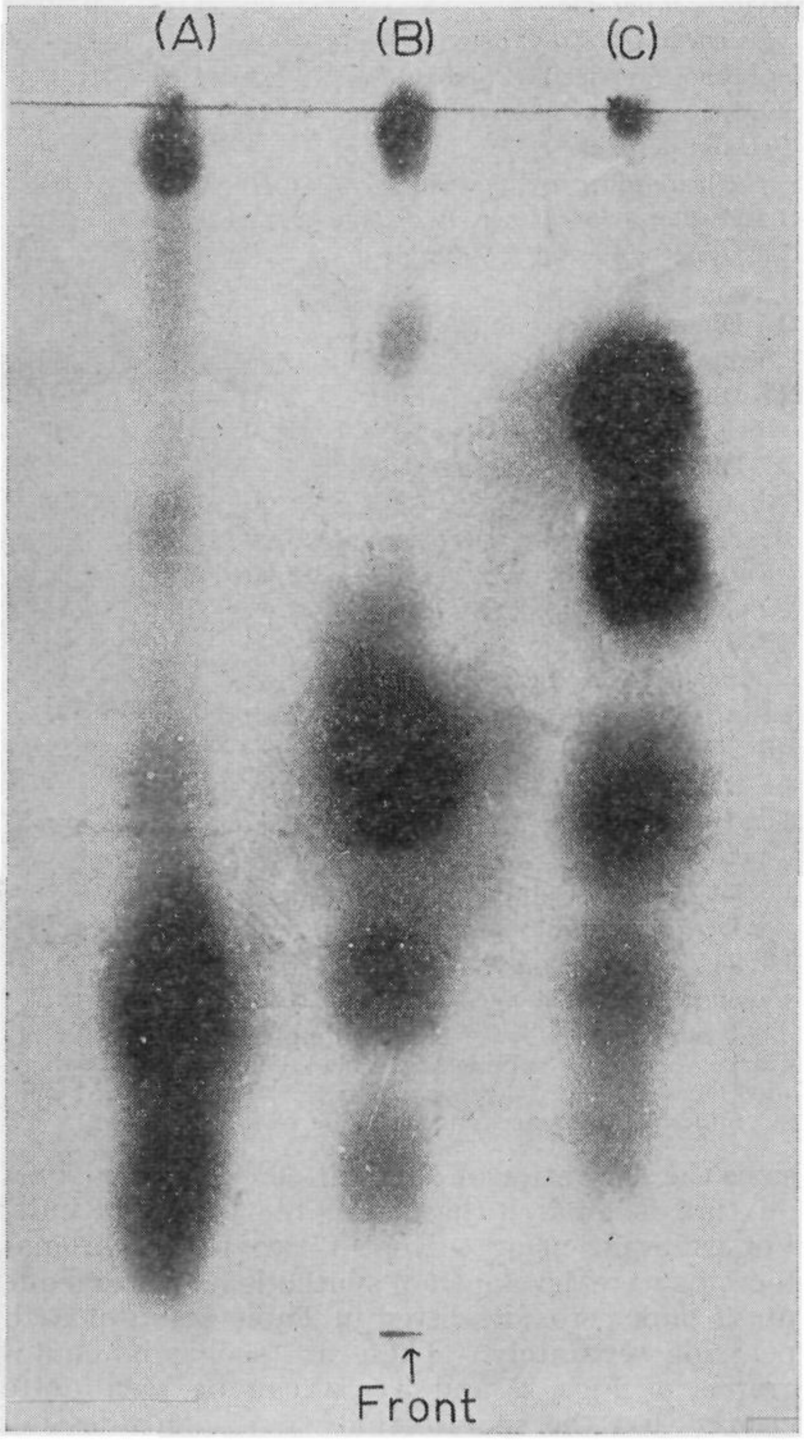

Fig. 1.—Paper chromatogram of ketone peroxides, 80 γ (crude): (A) from heptanone-2, (B) from diethyl ketone, (C) from methyl ethyl ketone.

The method of chromatostrip suggested by Kirchner, Miller and Keller[8] for the qualitative separation of terpenes has been applied recently to organic peroxides by Maruyama, Onone and Goto[9] who used silica gel and mixtures of silica gel and Celite as adsorbents. However, we have found this method cumbersome and the adsorbents unsuitable since they cause considerable decomposition of some of the peroxides we have investigated.

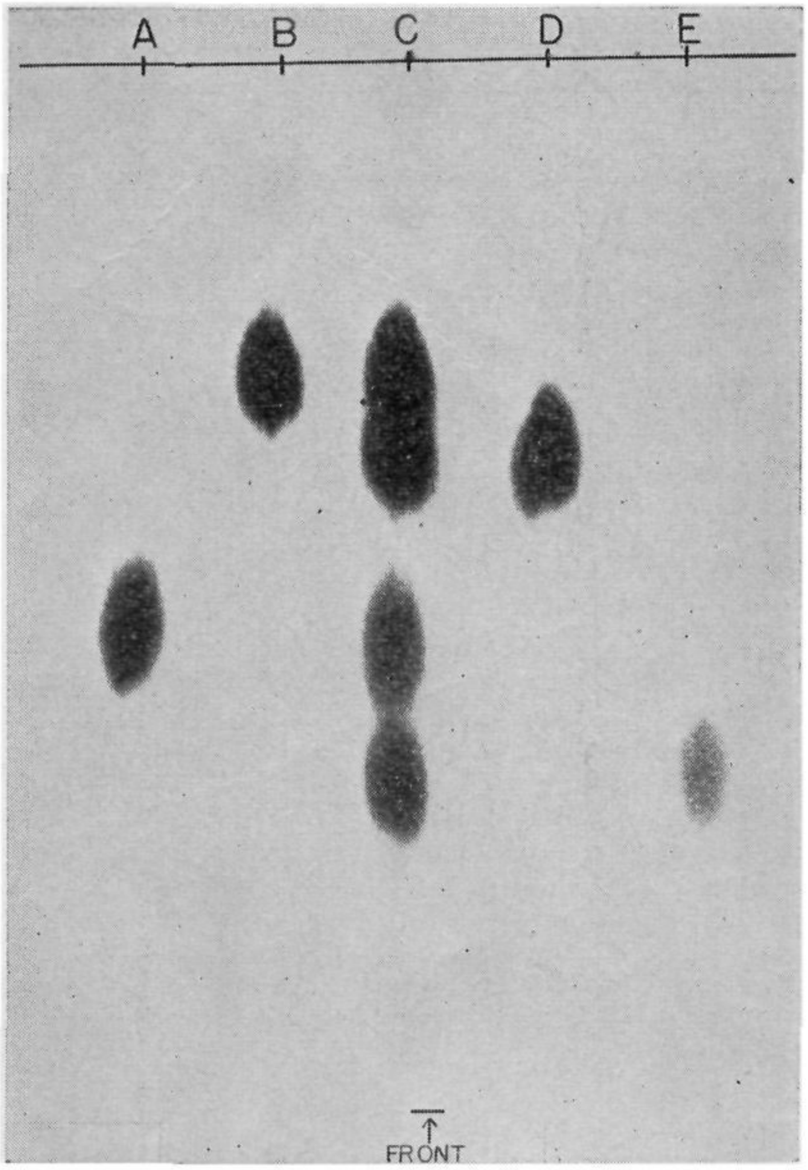

Fig. 2.—Paper chromatogram of: (A) *p,p'*-dichlorobenzoyl peroxide, (B) *M*-monomethoxybenzoyl peroxide; (C) *m*-monomethoxybenzoyl peroxide, benzoyl peroxide, *p,p'*-dichlorobenzoyl peroxide, 2,4-dichlorobenzoyl peroxide; (D) benzoyl peroxide; (E) 2,4-dichlorobenzoyl peroxide.

We have now successfully adapted the method of paper chromatography to guide us in the detection, separation and identification of organic peroxides formed from aliphatic ketones and hydrogen peroxide.[10] For example, of the several theoretically possible peroxides that can be produced from methyl ethyl ketone and diethyl ketone we have been able to detect six, and from heptanone-2 seven different peroxides. A photograph of a paper chromatogram of these peroxides is shown in Fig. 1.

Experimental

Equipment.—The usual equipment for descending chromatography was employed. Solutions of peroxides in hexane or methanol were applied with a micropipet on Whatman paper No. 1.

Solvents (All Percentages are in v./v.).—I, dimethylformamide–decalin as used by Sundt and Winter[11]; II, N-methyl-N-formamide–decalin (Sundt and Winter); III, *n*-butyl alcohol (45%), ethyl alcohol (5%), water (50%).

Detecting Agents.—1, *p*-aminodimethylaniline hydrochloride (Eastman Kodak Co.) (0.1%); 2, glacial acetic acid (3 cc.); satd. aqueous solution of potassium iodide (2 cc.); starch solution (5 cc.); 3, hydriodic acid (56%) (10 parts), glacial acetic acid (90 parts) (v./v.). All reagents should be freshly prepared before spraying.

Procedure.—The paper strip is irrigated with the solvent until the solvent front reaches a distance of 17–18 cm. from the point of application. Then the paper is dried in air for a short time to evaporate the excess solvent. It is not necessary to dry the paper completely, since the solvents used do not interfere with the formation of the color. The

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[8] J. G. Kirchner, J. M. Miller and G. J. Keller, *Anal. Chem.*, **23**, 420 (1951).

[9] K. Maruyama, K. Onone and R. Goto, *J. Chem. Soc. Japan*, **58**, 1496 (1956); *cf.* W. Eggersglüss, "Organische Peroxyde," Verlag Chemie, Weinheim, 1951.

[10] Paper XXIV, N. A. Milas and A. Golubović, THIS JOURNAL, **81**, 3361 (1959).

[11] E. Sundt and M. Winter, *Anal. Chem.*, **29**, 851 (1957).

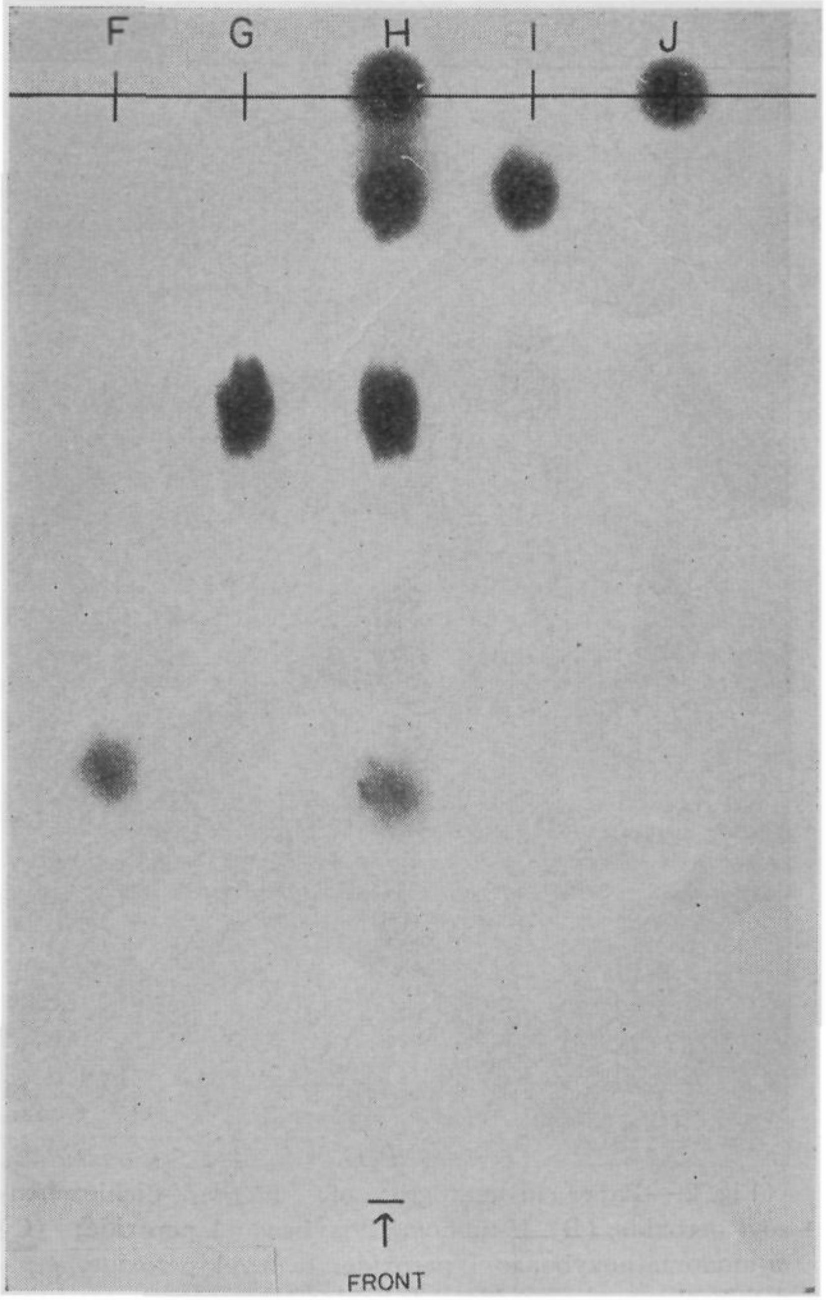

Fig. 3.—Paper chromatogram of: (F) *t*-butyl perbenzoate; (G) 2,5-dimethyl-3-hexyne 2,5-diperbenzoate; (H) *t*-butyl perbenzoate, 2,5-dimethyl-3-hexyne 2,5-diperbenzoate, cumene hydroperoxide, hydrogen peroxide; (I) cumene hydroperoxide; (J) hydrogen peroxide.

colored spots appear immediately after the spraying. With spray 1, however, the maximum color intensity is obtained after several minutes. For permanent records the spots should be circled with a pencil in order to determine the R_f, since the colored spots fade with time and a strongly colored background develops with sprays 2 and 3 but not with 1 although the spots of this also fade with time.

TABLE I

R_f VALUES OF PURE PEROXIDES

Peroxide	Solvent I	Solvent II	Solvent III
Hydrogen peroxide	0.00	0.00	0.49
p,p'-Dicyanobenzoyl peroxide[b]	.00	.01	0.0–0.50
m-Monocyanobenzoyl peroxide[b]	.20	.03	0.97
m-Monomethoxybenzoyl peroxide[b]	.29	.30	.94
Benzoyl peroxide[c]	.38	.37	.94
p,p'-Dichlorobenzoyl peroxide[b]	.56	.40	.94
2,4-Dichlorobenzoyl peroxide[c]	.69	.44	.94
2,5-Dimethylhexane 2,5-dihydroperoxide[c]	.00	.18	.89
2,5-Dimethyl-3-hexyne 2,5-dihydroperoxide[d]	.00	.17	.89
2,5-Dimethyl-3-hexyne 2,5-diperbenzoate[d]	.29	.24	.97
2,7-Dimethyl-3,5-octadyne 2,7-dihydroperoxide[d]	.00	.10	.92
Bis-(1-hydroxyheptyl) peroxide[c]	.00	.40	[a]
t-Butyl hydroperoxide[c]	.00	.00	[a]
Cumene hydroperoxide[e]	.09	.30	0.91[a]
t-Butylperoxymaleic acid[c]	.00	.10	.38
t-Butyl perbenzoate[c]	.63	.54	.95[a]
Lauroyl peroxide[c]	.98	.88	.97
t-Butyl peroxyisobutyrate[1]	[a]	..	[a]
3,3-Dihydroperoxy pentane[10]	0.02	..	..
3,3'-Dihydroperoxy-3,3'-dipentyl peroxide[10]	.53	..	..
1,1,4,4,7,7,10,10-Octaethyl-1,4,7-triperoxy 1,10-dihydroperoxide[10]	.86	..	...
1,1,4,4,7,7-Hexaethyl-1,4,7-cyclononatriperoxane[10]	.91	..	...

[a] Tested with 50 γ. [b] Kindly supplied by Dr. John T. Clarke. [c] Kindly supplied by Lucidol Division of Wallace and Tiernan, Inc. [d] Prepared by Dr. Orville L. Mageli. [e] Commercial cumene hydroperoxide.

Results and Discussion

It is well known that organic peroxides differ widely in their solubilities; consequently it is very difficult to find a single solvent which is satisfactory for all possible combinations. For this reason three different combinations of solvents were chosen and the R_f values of some peroxides of known structure and purity were first determined and are recorded in Table I. These values are determined with 10 γ of each peroxide. The sensitivity of the present method depends on the solvent and the spray used. For example, the smallest quantity of dibenzoyl peroxide which can be detected in the solvents I and III using sprays 1 or 2 is about 0.2 γ and at least 2 γ when spray 3 is used. With solvent II one can detect about 1 γ using spray 2. Of the three solvents used solvent I with sprays 1 or 2 gives the most useful results since the separation of different peroxides in a given mixture is greater than with the other solvents. For example, using solvent I two paper chromatograms were developed of synthetic mixtures made up of pure peroxides listed in Table I and of each peroxide separately. These are shown in photographs of Figs. 2 and 3. It can be seen quite clearly that the spots of individual peroxides fall exactly on the same position as the corresponding spots from the synthetic mixture. Furthermore, we have used this method successfully in guiding us in the chromatographic separation of several peroxides which are usually produced when various aliphatic ketones are allowed to react with hydrogen peroxide.[10] It must be pointed out, however, as it has been pointed out previously by Sundt and Winter,[11] that the R_f values determined with a two-phase system solvent are not absolute.

In the case of peroxides, which are very volatile under the experimental conditions described above, the limit of detectability is higher than that of dibenzoyl peroxide which was used as a standard. It is possible to detect such peroxides by increasing the amount of the sample applied on the paper or by shortening the time of developing. Such examples are *t*-butyl hydroperoxide, *t*-butyl perbenzoate and bis(1-hydroxyheptyl)peroxide. Peroxides with still higher volatility, such as *t*-butyl peroxyisobutyrate, are not easily detected by the combination of solvents used in the present method.

Acknowledgment.—The authors are indebted to Dr. A. Kalmus for some preliminary results with heptanone-2 and to Lucidol Division of Wallace and Tiernan, Inc., for financial support of this investigation.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY]

Studies in Organic Peroxides. XXIV. Preparation, Separation and Identification of Peroxides Derived from Diethyl Ketone and Hydrogen Peroxide

BY NICHOLAS A. MILAS AND ALEKSANDAR GOLUBOVIĆ[1]

RECEIVED DECEMBER 17, 1958

Several new peroxides have been isolated and definitely characterized from the reaction of diethyl ketone and hydrogen peroxide. A chromatographic method using cellulose powder as an adsorbent has also been developed and used in conjunction with paper chromatography to separate some of these peroxides in the pure form.

In the preceding publication[2] it was shown that paper chromatography can be used for the detection and separation of organic peroxides. We have now adapted this method to guide us in the detection, separation and identification of organic peroxides derived from diethyl ketone and hydrogen peroxide. The chromatogram B of Fig. 1 in the preceding paper shows the presence of five peroxides which are formed from this reaction as revealed when potassium iodide–glacial acetic acid was used as the detecting agent. A sixth peroxide which is not shown failed to develop a spot with the detecting agent used. However, when hydrogen iodide–glacial acetic acid was used as the detecting agent a new spot appeared corresponding to an R_f of 0.91 which was attributed to a trimeric peroxide I.

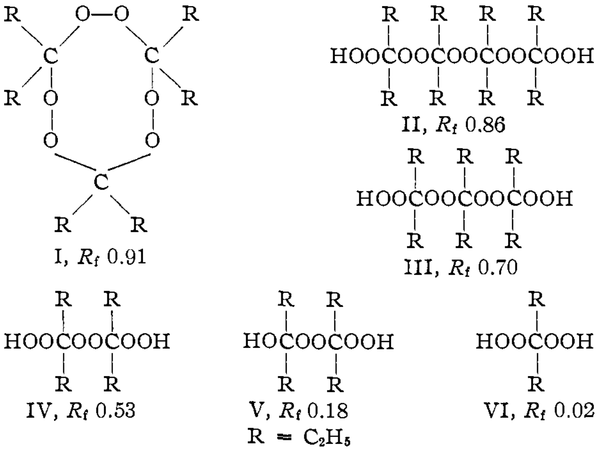

Fig. 1.—Peroxides derived from diethyl ketone and hydrogen peroxide.

When diethyl ketone was allowed to react at 0° with hydrogen peroxide in the presence of mineral acids a mixture of peroxides was obtained which was freed of excess hydrogen peroxide by extracting with a saturated ammonium sulfate solution dried and dissolved in petroleum ether. The mixture was chromatographed on a column of cellulose powder impregnated with dimethylformamide. The various peroxides were eluted with pentane saturated with dimethylformamide, and the fractions which gave single spots on paper chromatograms were combined and the pure peroxides isolated and identified by standard procedures. Of the six peroxides detected by paper chromatography, five have been separated and identified by this procedure and the sixth was detected but was too unstable to be isolated. They are labeled in the order in which they came out from the cellulose column. These are shown in Fig. 1.

The percentage of each peroxide present in the original mixture was estimated by paper chromatography and, in the above case, was found to be: I, 12.0; II, 0.4; III, 0.4; IV, 85.0; V, traces; and VI, 2.0%, respectively. Peroxides I, IV and VI could be separated from the mixture without resorting to cellulose powder chromatography. When the original mixture was dissolved in pentane and cooled to −70°, most of peroxide IV and traces of I separated as a crystalline mixture which could not be resolved into its pure components even after several crystallizations at low temperatures. However, when the crystalline mixture was subjected to sublimation at 3 mm. and at temperatures of 50–60°, the peroxide IV sublimed in the pure state and Compound I remained behind.

Peroxide VI failed to crystallize at low temperatures with IV and I, but when the mother liquor from the original crystallization was cooled to −70° and moist air was blown through the solution, a crystalline product separated out which, when dried in air at room temperature, analyzed as the monohydrate of peroxide VI. That this was the monohydrate was shown by removal of water at 40° under high vacuum and analyzing the residual gum. Moreover, when the gum was redissolved in pentane and moist air was blown through the solution, the monohydrate crystalline peroxide re-formed. The other peroxides in the mixture could be separated only by cellulose powder chromatography.

Although some of the peroxides shown in Fig. 1 are interconvertible, all are probably formed from the unstable 3-hydroxy-3-hydroperoxypentane (VII). In the cyclanone series it has already been shown[3,4] that the initial peroxide formed between a cyclanone and hydrogen peroxide is 1-hydroxy-

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[1] Lucidol Research Assistant.

[2] N. A. Milas and I. Belič, THIS JOURNAL, **81**, 3358 (1959).

[3] N. A. Milas, S. A. Harris and P. C. Panagiotakos, *ibid.*, **61**, 2430 (1939).

[4] N. A. Milas, U. S. Patent 2,298,405 (1942).