$\frac{D_t'D_m'' - D_t''D_m'}{D_c''D_m' - D_c'D_m''}$ and F is determined empirically from the calibration data in Table II. D_t, D_c and D_m are optical densities of pure *trans* isomer, pure *cis* isomer and a given mixture, respectively. The superscripts refer to absorption at the analytical wave lengths 13.40 μ(′) and 13.53 μ(″). The analytical solutions were in carbon disulfide and 2.0 mm. infrared cells were used. The optical density was taken to be zero at 11.0 μ. The total concentration used was 42 ± 2 mg./10.0 ml. of CS_2. The average value of F = 0.962 was used in calculating the results in the last two columns of Table II. The calibration runs in Table II indicate an estimated maximum error of ±0.8% *cis* isomer due to infrared uncertainties.

Acknowledgment.—The authors wish to express their gratitude to the Alfred P. Sloan Foundation for support of this research.

EVANSTON, ILLINOIS

[CONTRIBUTION NO. 168 FROM THE RESEARCH CENTER, UNITED STATES RUBBER CO.]

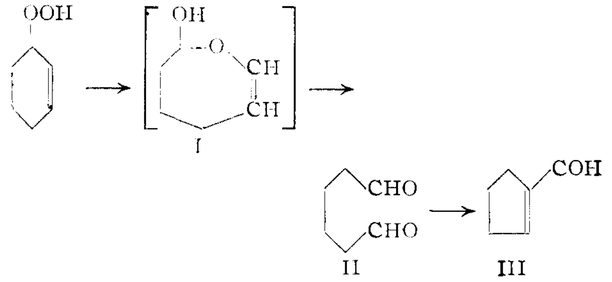
The Oxidation of Hydrocarbons. I. The Oxidation of Cyclohexene in Acetic and Propionic Anhydride Solutions[1]

BY HENRY J. SHINE[2] AND ROBERT H. SNYDER

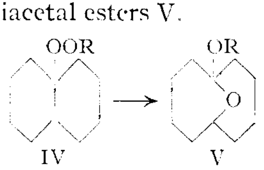
RECEIVED NOVEMBER 22, 1957

Cyclohexene has been oxidized at several temperatures in the range 25 to 80° in both acetic and propionic anhydride solutions by oxygen under free-radical initiation. Among the products isolated were the hitherto unknown esters, 3-oxa-4-cycloheptenyl acetate and propionate. These esters are stable over long periods of time in stoppered vessels. Detailed work on the acetic anhydride case has shown that cyclohexyl acetate also is formed. The nature of the oxidation is discussed.

The oxidation of cyclohexene and the decomposition of cyclohexene hydroperoxide[3] have been the subjects of many investigations. Among the products obtained are adipaldehyde (II) and cyclopentene-1-carboxaldehyde (III). It is customary to interpret[3] the formation of these aldehydes as arising from the decomposition of the cyclic intermediate I. This intermediate, however, never has been isolated, and no further evidence for its formation exists.



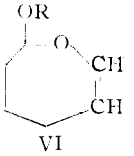
Cyclic compounds similar to the type I are not unknown in peroxide chemistry. For example, the esters IV of decalin hydroperoxide have been shown by Criegee[4,5] to rearrange to the corresponding cyclic hemiacetal esters V.



R = CH_3CO-, C_6H_5CO-, p-$NO_2C_6H_4CO-$

In the case of cyclohexene no peresters analogous to IV are known,[6] so that the preparation of esters analogous to V and corresponding with the parent compound I has not hitherto been possible.

As a consequence of work on the autoxidation of hydrocarbons we are now able to report the preparation of the esters VI by the oxidation of cyclohexene in acetic anhydride and in propionic anhydride. These esters are obtained in about 25% yield.



VIa, R = CH_3CO-
VIb, R = CH_3CH_2CO-

Assignment of the structure VI to the esters is based on work with VIa: Treatment with hydroxylamine hydrochloride gave the dioxime of adipaldehyde. This apparently involves hydrolysis of the ester followed by ring opening to adipaldehyde.

Treatment of VIa with acidified 2,4-dinitrophenylhydrazine gave the bis-2,4-dinitrophenylhydrazone of adipaldehyde and the 2,4-dinitrophenylhydrazone of cyclopentene-1-carboxaldehyde. The last compound apparently arises from the acid-catalyzed aldol condensation of adipaldehyde.

Oxidation of VIa by neutral potassium permanganate gave glutaric acid, apparently by oxidation of the double bond between positions 1 and 2 and oxidation at position 4.

Hydrogenation of VIa over Adams catalyst gave 1,6-hexandiol and acetic acid. Hydrogenation over palladium black gave the saturated ester VII. Treatment of VII with 2,4-dinitrophenylhydrazine gave the 2,4-dinitrophenylhydrazone of 6-hydroxyhexanal.

In the case of VIb the structure is assigned from analysis and from the formation of the 2,4-dinitro-

---

[1] Presented before the Division of Organic Chemistry at the 132nd Meeting of the American Chemical Society, New York, N. Y., Sept., 1957.

[2] Department of Chemistry, Texas Technological College, Lubbock, Texas. Please address requests for reprints to Library, U. S. Rubber Co., Research Center, Wayne, N. J.

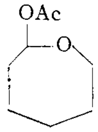
[3] For pertinent references to these investigations, particularly the outstanding work of Farmer's group, reference should be made to the review by E. G. E. Hawkins, *Quart. Revs.*, **4** (1950), and to the discussion of autoxidation by W. A. Waters, "Chemistry of Free Radicals," 2nd ed., Oxford, Clarendon Press, 1948, pp. 226-258.

[4] R. Criegee, *Ber.*, **77**, 722 (1944).

[5] R. Criegee and R. Kaspar, *Ann.*, **560**, 127 (1948).

[6] R. F. Naylor, *J. Chem. Soc.*, 244 (1945), reported obtaining a small amount of material, believed to be cyclohexenyl peracetate, by the action of ketene on cyclohexene hydroperoxide at −70°. The difficulty in isolating the perester was attributed to the ease with which it was believed to decompose to cyclohexenyl acetate.

phenylhydrazones of adipaldehyde and cyclopentane-1-carboxaldehyde on treatment with acidified 2,4-dinitrophenylhydrazine.



VII

From the oxidation of cyclohexene in acetic anhydride there was obtained, besides VIa, both cyclohexene-3-one and cyclohexyl acetate. No cyclohexenyl acetate could be found, although we cannot say with certainty that none was present.

Experimental[7]

Oxidation of Cyclohexene in Acetic Anhydride (I).—The influence of acetic anhydride on the oxidation of cyclohexene was first observed in oxidations carried out under pressure. Cyclohexene, containing azo-bis-isobutyronitrile, was heated at 60° for several hours under 2 to 3 atmospheres of oxygen pressure. Very little oxygen was absorbed and most of the cyclohexene was recovered. Under similar conditions, the use of a solution of cyclohexene in acetic anhydride caused a considerable increase in the amount and rate of oxygen absorption. Removal of unchanged cyclohexene and acetic anhydride as well as the acetic acid formed during oxidation left a mixture of products from which was separated by fractional distillation a sweet-smelling liquid, b.p. 52° (3 mm.), $n^{20}{}_{D}$ 1.4580, shown subsequently to be VIa. All further oxidations were carried out at atmospheric pressure.

Oxidation of Cyclohexene in Acetic Anhydride (2).—A mixture of 672 (8.2 moles) of distilled cyclohexene, 1420 g. (13.9 moles) of acetic anhydride and 1 g. (0.006 mole) of azo-bis-isobutyronitrile was brought to 77° and kept at that temperature for 48 hours during which time a further 2 g. of catalyst was added in three portions and oxygen was bubbled continuously through the solution. After 48 hours the amber solution was allowed to cool and was freed of unused cyclohexene, acetic acid and unused acetic anhydride under reduced pressure, the pot temperature being kept below 50°. Fractional distillation of the mixture of cyclohexene, acetic acid and acetic anhydride gave an azeotrope of cyclohexene and acetic acid from which the acetic acid was removed by treatment with excess potassium carbonate. After redistillation the recovered cyclohexene weighed 355 g. The mixture of products, weighing 700 g., remaining, was fractionally distilled at reduced pressure, and, after grouping fractions by boiling point and refractive index, the following were obtained: (A) a mixture of cyclohexyl acetate and cyclohexene-3-one, b.p. 53° (35 mm.) to 38° (8 mm.), $n^{20}{}_{D}$ 1.4400 to 1.4682, 318 g.; (B) 3-oxa-4-cycloheptenyl acetate (VIa), b.p. 52–53° (3 mm.), $n^{20}{}_{D}$ 1.4580, $d^{20}{}_{20}$ 1.0756, 162 g. (25% yield); (C) higher boiling products, unidentified, b.p. 54–101° (3 mm.), 90 g.; and (D) an undistillable residue, 127 g.

Fractionation of (A) at atmospheric pressure gave cyclohexyl acetate and cyclohexene-3-one. The ketone was identified as its 2,4-dinitrophenylhydrazone. Various melting points have been reported in the literature for this derivative, ranging from 113 to 170°.[8] We find that the derivative crystallizes in two forms: blood-red prisms from concentrated ethanol solution, having m.p. 170–171°, and orange, very long, hair-like crystals from dilute ethanol, having m.p. 169.5–170.5°. A mixture of the two forms had m.p. 169–170°.

Cyclohexyl acetate was identified by its physical constants, b.p. 174° (750 mm.), $n^{20}{}_{D}$ 1.4412; an authentic sample had b.p. 174° (750 mm.), $n^{20}{}_{D}$ 1.4426; and by comparison of its infrared spectrum with that of the authentic material. Base hydrolysis gave cyclohexanol; phenylurethan, m.p. 85°.

Oxidation of Cyclohexene in Acetic Anhydride (2). Ultraviolet Light Initiation.—A reaction vessel similar to that described by Kharasch and Friedlander[9] was used. The use of ultraviolet light as the source of radical initiation rather than a temperature-dependent catalyst decomposition enabled working at several temperatures, from which representative results are given below. From the oxidation of solutions of 246 g. (3 moles) of cyclohexene in 459 g. (4.5 moles) of acetic anhydride were obtained: at 25°, (A) 8 g., (B) 12 g., (C and D) 8 g.; at 50°, (A) 10 g., (B) 32 g., (C and D) 25 g.; at 80°, (A) 32 g., (B) 37 g., (C and D) 68 g.

Identification of (B) as 3-Oxa-4-cycloheptenyl Acetate (VIa).—*Anal.* Calcd. for $C_8H_{12}O_3$: C, 61.52; H, 7.69; *MR*, 39.6. Found: C, 61.61; H, 7.63; *MR*, 39.65.

2,4-Dinitrophenylhydrazone.—A warm solution of 2,4-dinitrophenylhydrazine in acidified ethanol was added to a solution of (B) in ethanol causing the rapid precipitation of the fine yellow derivative of adipaldehyde, which after recrystallization from nitrobenzene had m.p. 233–234° dec.

The red filtrate deposited fine red needles on standing a short time. Recrystallization from a large volume of hot ethanol gave the derivative of cyclopentene-1-carboxaldehyde, m.p. 206–207° dec.

Oxime.—An alkaline solution of hydroxylamine hydrochloride was added to an ethanol solution of (B) and warmed for 10 min. on the steam-bath. On standing, the solution deposited colorless crystals of adipaldehyde dioxime, m.p. 178–179°. Crystallization from hot water did not change the melting point.

Elemental analyses of the three derivatives above were in excellent agreement with calculated values. The derivatives also were found to be identical with authentic specimens.

Oxidation of (B) with Potassium Permanganate.—To a stirred suspension of 3 g. of (B) in an aqueous solution of magnesium sulfate was added potassium permanganate in small portions until the purple permanganate color disappeared only on long standing. Removal of the manganese dioxide by centrifugation, and distillation of the aqueous solution to dryness under reduced pressure left a brown solid residue. This was extracted with ethyl acetate, and, after drying, the ethyl acetate solution was evaporated to dryness. A white solid was obtained, which on recrystallization from a large volume of benzene had m.p. 92–94°. The solid was found to have a neutral equivalent of 65.8 (glutaric acid, 66) and gave a *p*-bromophenacyl ester, melting point and melting point of mixture with authentic ester, 136°.

Hydrogenation of (B). With Platinum Oxide Catalyst.—A solution of 67.5 g. of (B) in 100 ml. of 95% ethanol was hydrogenated over 0.2 g. of platinum black in a Parr pressure apparatus. Fractional distillation of the product under reduced pressure gave 34.5 g. of liquid mixture containing acetic acid (identified by the preparation of the *p*-bromophenacyl ester, m.p. and mixed m.p., 86°), and 8 g. of low melting solid, m.p. 37–40°, found to be 1,6-hexanediol by the preparation of the bisphenylurethan, melting point and melting point of mixture with authentic derivative, 169–170°.

With Palladium Oxide Catalyst.—A solution of 28.7 g. of (B) in 75 ml. of 95% ethanol was hydrogenated over 1 g. of 10% palladium oxide on charcoal. Fractional distillation of the product under reduced pressure gave 16 g. of sweet-smelling liquid (VII), b.p. 61–62° (3 mm.), $n^{20}{}_{D}$ 1.4472.

Anal. Calcd. for $C_8H_{14}O_3$: C, 60.7; H, 8.86. Found: C, 60.93; H, 8.48.

Addition of acidified solution of 2,4-dinitrophenylhydrazine to a solution of the hydrogenation product gave the bright yellow, very soluble derivative of 6-hydroxyhexanal, which, on crystallization from aqueous ethanol, had m.p. 103°.

Anal. Calcd. for $C_{12}H_{16}N_4O_5$: C, 48.6; H, 5.45; N, 18.9. Found: C, 48.83; H, 5.40; N, 18.85.

Hydrolysis of (B).—To 5 ml. of 10% sodium carbonate solution was added 0.1 g of (B). The mixture was shaken overnight at room temperature to give a suspension of yellow globules having a strong almond odor. The mixture was extracted with ligroin and the ligroin solution was evaporated to give a yellow oil. Addition of acidified 2,4-dinitrophenylhydrazine solution to this caused the rapid formation of the yellow derivative of adipaldehyde, m.p. 236–238° dec. Concentration of the filtrate gave red needles,

---

[7] Microanalyses by Schwarzkopf Laboratories, Woodside 77, N. Y.

[8] M. W. Cronyn and J. E. Goodrich, This Journal, **74**, 3331 (1952).

[9] M. S. Kharasch and H. N. Friedlander, *J. Org. Chem.*, **14**, 239 (1949).

m.p. 207–209° dec., unchanged by crystallization from hot ethanol.

Oxidation of Cyclohexene in Propionic Anhydride.—This oxidation was carried out in the ultraviolet irradiation apparatus. A solution of 197 g. (2.4 moles) of cyclohexene in 468 g. (3.9 moles) of propionic anhydride was irradiated at 50–60° for 24 hours, oxygen being passed through the solution continuously. Fractional distillation gave 28.5 g. (22% yield) of 3-oxa-4-cycloheptenyl propionate (VIb), b.p. 44–48° (0.5 mm.), n^{20}_{D} 1.4586.

Anal. Calcd for $C_9H_{14}O_3$: C, 63.53; H, 8.24. Found: C, 63.64; H, 8.34.

Treatment of VIb with acidified 2,4-dinitrophenylhydrazine gave the yellow derivative of adipaldehyde, m.p. 236–237° dec., and the red derivative of cyclopentene-1-carboxaldehyde, m.p. 206–207° dec.

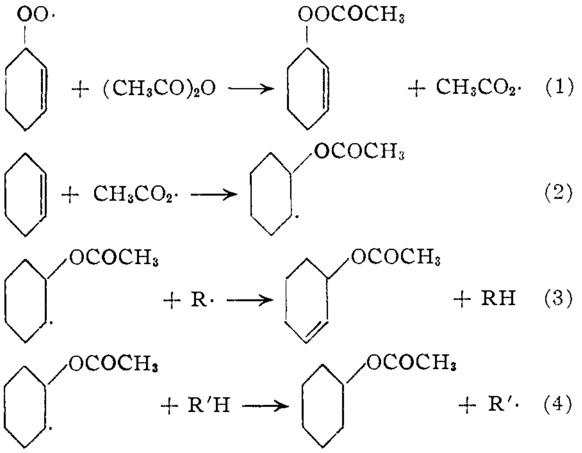
No attempt was made to isolate cyclohexyl propionate and cyclohexene-3-one in this case.

Discussion

The formation of the esters VIa and VIb may be explained by the rearrangement of the first-formed peresters of cyclohexene hydroperoxide. The formation of cyclohexene-3-one may be explained as described by Criegee[4] for α-tetralone. The formation of cyclohexyl acetate and the influence of acetic anhydride on oxygen uptake are particularly noteworthy. Kharasch and Burt[10] report that the two major products of acid-catalyzed decomposition of cyclohexene hydroperoxide in acetic acid are cyclohexenyl acetate and cyclopentene-1-carboxaldehyde. No cyclohexyl acetate was obtained. In the present work cyclohexyl acetate was a major product, while no cyclohexenyl acetate could be found; we are not certain that the latter was absent, however.

The following sequences indicate one possible reaction path, of the several under consideration, which can account for our observations.

The perester in equation 1 is free to undergo rearrangement to VIa. The cyclohexenyl peroxy radicals in equation 1 are formed by the customary steps. The acetoxy radicals generated in equation 1 react as acetoxy radicals rather than decomposing. They account for the cyclohexyl acetate obtained and, probably, are also responsible, by hydrogen abstraction from cyclohexene, for much of the acetic acid obtained. It is believed that the apparent absence of cyclohexenyl acetate from the oxidation products is due to further oxidation of this unsaturated ester. Work is in progress on this point. It is possible that the R'H in equation 4 is cyclohexene. Independent evidence for the validity of reactions 2, 3 and 4 has been obtained.[11]



In a later paper the extension of this oxidation to other hydrocarbons will be reported.

Acknowledgments.—The continuous encouragement and advice from Dr. P. O. Tawney during the course of this work are gratefully acknowledged. The authors also wish to thank Mr. C. H. Stiteler and Mr. K. A. Leibbrand for technical assistance. Spectrographic work was performed by Mr. R. R. Hampton, Mr. C. L. Hilton and Miss J. E. Wilson.

WAYNE, NEW JERSEY

---

[10] M. S. Kharasch and J. G. Burt, *J. Org. Chem.*, **16**, 150 (1951).

[11] H. J. Shine and J. R. Slagle, unpublished work.

[CONTRIBUTION FROM THE RESEARCH INSTITUTE FOR TROPICAL MEDICINE, CAIRO]

The Reaction of α-Ethoxymethylenecarboxylic Esters with Some Cyclic Amidines

BY H. ANTAKI

RECEIVED OCTOBER 15, 1957

The condensation of ethyl ethoxymethyleneacetoacetate and cyanoacetate with 2-aminopyridine and its 3-, 4- and 6-methyl derivatives gives the corresponding ethyl 2-pyridylaminomethyleneacetoacetates and cyanoacetates. These esters were cyclized by distillation under reduced pressure to the respective 4H-pyrido[1,2-a]pyrimidines. 2-Aminoquinoline behaves similarly. The ultraviolet absorption spectra of the compounds have been determined and are discussed in relation to their structures.

The reaction between ethyl ethoxymethylenemalonate and 2-aminopyridine and its derivatives[1–2] has been reported to proceed through the intermediate ethyl 2-pyridylaminomethylenemalonate which cyclized in diphenyl ether to ethyl 4 - ketopyrido[1,2-a]pyrimidine - 3 - carboxylate. 6-Substituted-2-aminopyridines on the other hand give 1,8-naphthyridines,[3–7] a behavior ascribed to steric hindrance coupled with activation of the 3-position through electron release by the 6-substituent. The reaction has now been extended to ethyl ethoxymethyleneacetoacetate and cyanoacetate in view of the observation that the pyrido[1,2-a]pyrimidines previously reported[8] produced the so-

---

[1] G. Lappin, THIS JOURNAL, **70**, 3348 (1948).

[2] R. Adams and I. Pachter, *ibid.*, **74**, 5491 (1952).

[3] V. Petrow, E. L. Rewald and B. Sturgeon, *J. Chem. Soc.*, 1407 (1947).

[4] A. Mangini and A. Colonna, *Gazz. chim. ital.*, **72**, 183 (1942); *Chem. Zentr.*, 111 **II**, 2613 (1940).

[5] E. Ochiai and K. Miyaki, *Ber.*, **74**, 1115 (1941).

[6] R. Adams, THIS JOURNAL, **68**, 1317 (1946).

[7] O. Seide, *Ber.*, **59**, 2465 (1926).

[8] H. Antaki and V. Petrow, *J. Chem. Soc.* 551 (1951).