Thanks are due the du Pont Co. for a Predoctoral Fellowship (T.R.) and for a du Pont Summer Faculty Fellowship (F.V.B., Jr.), the University of Pennsylvania for an Edgar Fahs Smith Summer Fellowship (N.P.) and for a University Undergraduate Senior Research Scholarship (S.J.B.) and the Hercules Powder Co. for a Summer Faculty Fellowship (F.V.B., Jr.,).

Experimental[36]

d-α-Bromocamphor was prepared from d-camphor (Eastman Kodak Co.) as recorded elsewhere,[37] m.p. 75–76°, lit. m.p. 76–77°.

d-α,α'-Dibromocamphor was prepared from d-α-bromocamphor as in the literature,[38] m.p. 61°, lit. m.p. 60°.

d-α-Chlorocamphor.—Preparation was effected from d-camphor essentially as described by Kipping and Pope,[39] m.p. 94.5–95°, lit. m.p. 93.5°.

d-α'-Chlorocamphor was prepared from d-α-chlorocamphor as described by Lowry and Steele,[40] m.p. 117°, lit. m.p. 117°.

d-α,α'-Dichlorocamphor, prepared from d-camphor by direct halogenation,[41] had m.p. 95.5–96°, lit. m.p. 96°.

2-Indanone, prepared as mentioned in footnote *b*, Table I, had m.p. 56.4–57°, lit.[42] m.p. 56–57°.

1-Bromo-2-indanone.—Preparation was effected from 2-indanone as described by Creeth and Thorpe,[43] m.p. 91°, lit. m.p. 91°.

1-Chloro-2-Indanone.—One gram (0.0076 mole) of 2-indanone was dissolved in 5 ml. of chloroform. Chlorine was passed into the solution for five minutes. The solvent was evaporated and the residue was recrystallized from benzene to remove unreacted 2-indanone. The material was then recrystallized twice from ligroin (65–110°). The colorless prisms melted at 71–71.5°. *Anal.* Calcd. for C_9H_7OCl: C, 64.89; H, 4.24; Cl, 21.28. Found: C, 64.61; H, 4.23; Cl, 21.33, 21.39.

2-Bromocyclopentanone was prepared as described elsewhere,[9c] b.p. 67° (5 mm.), $n^{20}D$ 1.5085, lit.[9c] b.p. 82–83° (12 mm.), $n^{18.5}D$ 1.4778.

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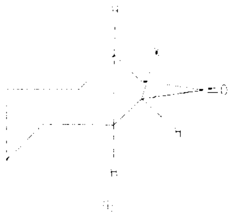
We get shifts in iii of 9 cm.$^{-1}$ for α-bromine and 14 cm.$^{-1}$ for α-chlorine. These are almost identical with the simple α-halocyclopentanones. This further suggests that 16-ketosteroids would prefer the half-chair conformation.



[36] All melting points are uncorrected.

[37] J. E. Marsh, *J. Chem. Soc.*, 828 (1890).

[38] T. M. Lowry, *ibid.*, 569 (1898).

[39] K. Kipping and W. Pope, *ibid.*, 548 (1893).

[40] J. Lowry and R. Steele, *ibid.*, 1382 (1915).

[41] P. Cazeneuve, *Compt. rend.*, **94**, 731 (1882).

[42] N. Levin, B. E. Graham and H. G. Kolloff, *J. Org. Chem.*, **9**, 380 (1944).

[43] N. Creeth and J. Thorpe, *J. Chem. Soc.*, 1507 (1908).

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, IOWA STATE UNIVERSITY]

Cyclopentene-3,5-dione. I. Synthesis and Properties[1]

BY C. H. DEPUY AND E. F. ZAWESKI[2]

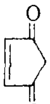
RECEIVED FEBRUARY 19, 1959

Cyclopentene-3,5-dione (I) has been prepared by oxidation of the corresponding diol. Attempts to prepare it by base-promoted elimination reactions led instead, or concurrently, to cyclopentadienone, isolated as its dimer. The dione is very acidic, although less so than the saturated dione. No evidence has been found for the existence of the enol form. The dione polymerizes readily in basic solution, possibly by Michael addition, but is stable toward acid. Some chemical and spectral properties of the compound are discussed, as well as the question of the stability of cyclopentadienone.

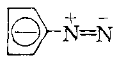
Introduction

Over the past ten years a tremendous amount of work has been carried out on the synthesis and reactions of highly unsaturated seven-membered ring compounds. This work has led to a completely new type of chemistry, and to new aromatic and pseudoaromatic ring systems. Although similarly interesting and unusual unsaturated *five-membered* ring compounds might be imagined, little synthetic work has so far appeared. In this paper we describe the synthesis and some of the properties of cyclopentene-3,5-dione (I), a molecule with a great deal of interest in its own right, and one which we anticipate will be a suitable starting material for the preparation of other molecules of theoretical and practical importance.

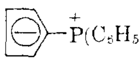
We considered cyclopentene-3,5-dione to be a potentially useful molecule for a number of reasons. First the only stable, completely unsaturated cyclopentane compounds known are those which are substituted with electron-donating groups (*i.e.*, diazocyclopentadiene[3] (II) and triphenylphosphonium cyclopentadienylide[4] (III)). These compounds so far have not proved amenable to further elaboration.



I



II



III

Secondly monosubstituted cyclopentadienes are susceptible to dimerization, and the mobility of the protons in a cyclopentadiene ring makes the isolation of a pure isomer difficult.[5] These considerations led us to the synthesis of the dione, which

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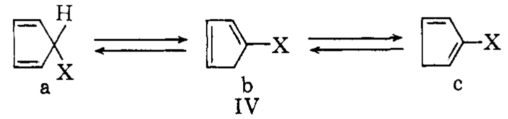
[1] A preliminary announcement of some of this work appeared as a "Communication to the Editor" in THIS JOURNAL, **79**, 3923 (1957).

[2] Procter and Gamble Fellow, Summer, 1958.

[3] W. von E. Doering and C. H. DePuy, THIS JOURNAL, **75**, 5955 (1953).

[4] F. Ramirez and S. Levy, *ibid.*, **79**, 67 (1957).

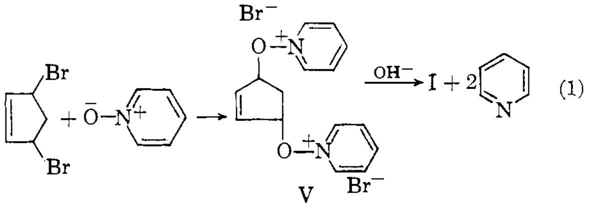
[5] For examples of this equilibrium see M. Rosenblum, *ibid.*, **79**, 3179 (1957), and R. J. Day, *Dissertation Abst.*, **19**, 39 (1950). We have observed a similar mixture of products from the pyrolysis of 3,5-diacetoxycyclopentene (C. H. DePuy, unpublished results). It seems probable that compounds of the type IVa would be relatively stable if they could be formed at moderate temperatures in the absence of bases.



IV

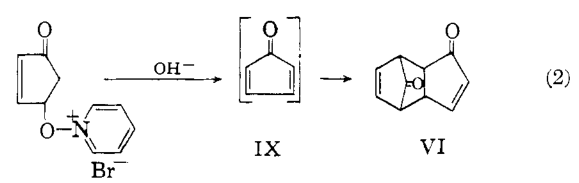
contains neither an intact cyclopentadiene ring, nor a completely unsaturated ring but which because it contains three different kinds of functional groups, and because all of its carbon atoms are potentially reactive, should prove to be an ideal starting material for syntheses in this field.

Method of Synthesis.—It has been demonstrated recently that low temperature bromination of cyclopentadiene leads to the formation of *cis*-3,5-dibromocyclopentene.[6] We chose to work with the pure *cis* isomer so that our later experiments would not be complicated by the presence of diastereomers. Later work (*vide infra*) shows that the synthesis would be successful with a mixture of *cis*- and *trans*-alcohols. We first tried to prepare the dione from the dibromide by the sequence shown in equation 1. The decomposition of O-alkylpyridines



(*i.e.*, V) to carbonyl compounds is a well documented reaction[7,8] which has not found appreciable synthetic utility.[9] Reaction of the dibromide with two moles of pyridine N-oxide in benzene led to the immediate precipitate of a salt-like tan solid which, while not amenable to purification, analyzed reasonably well for V. Decomposition of V with aqueous base led mainly to polymeric material from which, by continuous ether extraction, variable small amounts of a white crystalline solid, m.p. 96–98°, could be isolated. This solid exhibited infrared absorption maxima at 5.60 and 5.85 μ, and analytical and molecular weight determinations indicated a formula $C_{10}H_8O_2$. The compound was identified as the dimer of cyclopentadienone (VI) by comparison with an authentic sample[10] prepared by the hydrolysis of the corresponding dioxime.[11]

The yields of the dimeric ketone varied from zero to 13% in a number of runs, and one reasonable path for its formation is given in equation (2).[12]



The formation of appreciable quantities of reaction products of cyclopentadienone suggests that it will not prove impossible to form this interesting molecule, at least transiently, and that there is no insuperable barrier to the introduction of the second double bond.

With the failure of this short cut, the synthesis of I was accomplished by more conventional means. The 3,5-dibromide was converted to the 3,5-diacetate with tetraethylammonium acetate in dry acetone,[13] conditions which minimize rearrangement of the dibromide, and the diacetate hydrolyzed to cyclopentene-3,5-diol.[14] Oxidation of the diol with CrO_3 in acetic acid or acetone led to the dione in yields of about 50%. After we had published our original communication on the synthesis of the dione,[1] a synthetic mixture of cyclopentenediols became available commercially.[15] Vacuum distillation of the mixture of diols through a spinning brush column of approximately twenty plates cleanly separates the 3,4- and 3,5-cyclopentenediols. Oxidation of the 3,5-diol (presumably a mixture of *cis* and *trans*) gave the dione in yields comparable to those obtained by the oxidation of the pure *cis*-diol. Cyclopentene-3,5-dione is therefore available in 40–50% yield from commercially available material.

Properties.—Cyclopentenedione is a yellow, volatile solid melting at 37–38° and soluble in water and most organic solvents except hydrocarbons. The yellow color is due to two low intensity bands at 322 mμ (log ε 1.30) and 367 mμ (log ε 1.30). It also exhibits a strong absorption maximum at 222 mμ (log ε 4.16). In the infrared there are two peaks in the C=O region in $CHCl_3$ solution, a strong absorption at 5.83 μ and a medium one at 5.73 μ.[16] In the vapor phase there is a single peak at 5.82 μ.[17]

One other physical property of the dione that is of interest is the dissociation constant. Unfortunately it has not been possible to determine this accurately because of the rapid polymerization of the dione in basic solution. Studies of the acidity of the dione in 0.1 N aqueous solution suggests that a pK_a of 6 is a reasonable value. The dione will liberate CO_2 from HCO_3^- solution. Although this

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[6] W. G. Young, H. K. Hall and S. Winstein, THIS JOURNAL, **78**, 4338 (1956).

[7] E. Ochiai, M. Kotada and T. Naito, *J. Pharm. Soc. Japan*, **64A**, 210 (1944).

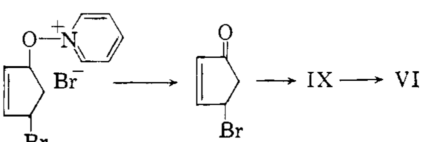
[8] R. Rolih, Dissertation, Iowa State College, 1956.

[9] For a mechanistically similar reaction, which has been suggested to have synthetic utility, see N. Kornblum, *et al.*, THIS JOURNAL, **79**, 6526 (1957).

[10] C. H. DePuy and B. W. Ponder, *ibid.*, **81**, 4629 (1959).

[11] J. Thiele, *Ber.*, **33**, 669 (1900).

[12] An alternate attractive source of VI might have been from small, variable amounts of the bromoketone VII, arising from material in which only one bromine had been replaced by the N-oxide. This



VII

explanation was made unlikely by the observation that no dimeric ketone could be isolated from experiments in which the dibromide was treated with one mole of pyridine N-oxide and then base.

[13] L. N. Owen and P. N. Smith, *J. Chem. Soc.*, 4043 (1952).

[14] G. O. Schenck and D. E. Dunlap, *Angew. Chem.*, **68**, 248 (1956).

[15] Columbia Southern Chemical Co., One Gateway Center, Pittsburgh, Pa.

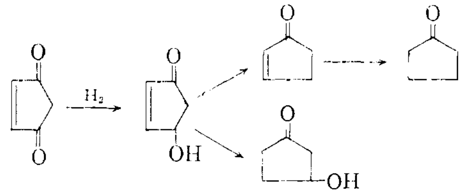
[16] (a) R. N. Jones in "Techniques of Organic Chemistry," Vol. IX, Interscience Publishers, Inc., New York, N. Y., 1956, p. 495; (b) H. K. Hall, Jr., and R. Zbinden, THIS JOURNAL, **80**, 6428 (1958).

[17] The disappearance of the lower intensity carbonyl absorption may be due to the more rigid operation of selection rules in the vapor phase.

value may be somewhat in error, it probably does not differ from the true value by more than one pK_a unit.

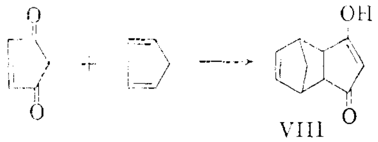
Chemically, cyclopentene-3,5-dione is extremely reactive under most conditions. Reactions at the carbonyl group are complicated by the fact that in the presence of even small amounts of base the dione rapidly polymerizes. Addition of a drop of piperidine to a benzene solution of the dione results in the rapid precipitation of an enolic, water-soluble polymer. Similar reactions take place in water and in other solvents. We will defer discussion of condensation reactions for future publications.

Reductions.—The enedione may be reduced to the known[18] cyclopentane-1,3-dione in 45% yield by zinc dust in acetic acid. Polymeric material is also formed, and polymer is the exclusive product unless the dione is added *to* the hot mixture of zinc and acid. If the enedione is reduced catalytically with Adams catalyst, approximately 2.7 molar equivalents of H_2 are absorbed without an appreciable break in the rate of H_2 uptake. Less than 2% of cyclopentane-1,3-dione is formed, as measured by base titration of the product. Gas chromatography and infrared spectra indicate that cyclopentanone and β-hydroxycyclopentanone are formed in roughly equal amounts. This was confirmed by the preparation and chromatography of the 2,4-dinitrophenylhydrazones. Cyclopentanone 2,4-DNP and cyclopentenone 2,4-DNP (formed by dehydration of the β-hydroxycyclopentanone under the experimental condition) were isolated in about equal amounts. The apparent course of the hydrogenation is shown in equation 3.



(3)

Diels-Alder Reaction.—As would be expected, cyclopentene-3,5-dione is a very reactive dienophile. It reacts immediately and quantitatively with cyclopentadiene to form an adduct (VIII).



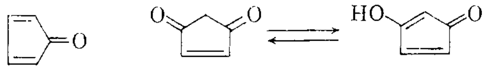
VIII

Like cyclopentane-1,3-dione, the adduct is completely enolic. With anthracene the reaction is slower, but an adduct is formed in 90% yield after four days in refluxing benzene. This is an excellent method for preparing a variety of substituted cyclopentane-1,3-diones, which are otherwise very difficult to form. We have made use of the enolic property of the dione adduct VIII to compare the reactivity of I with that of maleic anhydride. Equimolar amounts of I and maleic anhydride were allowed to compete for one molar equivalent of cyclopentadiene and the amount of VIII in the product was determined colorimetrically by the use of $FeCl_3$. These competition experiments showed that maleic anhydride was four times more reactive than I toward cyclopentadiene.

Carbonyl Addition Reactions.—The carbonyl groups of I are extremely reactive, and mono- and dicarbonyl derivatives are formed immediately. Mono- and/or dioximes, phenylhydrazones, *p*-toluenesulfonhydrazones and O-methyloximes have been prepared. In each case infrared spectral data and analyses show that addition has taken place to the carbonyl group, and not to the double bond, although it seems likely that the double bond would be active toward Michael additions. It appears probable that Michael addition is important in the polymerization of the dione in basic solution, for in that case, in dilute solution, an enolic, water-soluble product is formed which contains more oxygen than the original dione.

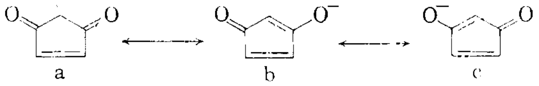
Discussion

In addition to its interest as a synthetic intermediate, cyclopentene-3,5-dione presents the opportunity for investigation of certain problems of theoretical interest. These problems arise primarily because of the relationship of I to cyclopentadienone (IX). This dienone, and its simply substituted derivatives, is unknown and presumably unstable for electronic reasons.[19] In its enol form, cyclopentene-3,5-dione would be a hydroxycyclopentadienone.



IX I X

It seems significant then that the dione appears to be close to 100% ketonic, with no detectable enol content by infrared or n.m.r.[20] spectra. It does not give a color with ferric chloride. Its dihydro derivative cyclopentane-1,3-dione is completely enolic under the same conditions. This would suggest that the cyclopentadienone structure is indeed of high energy. The data on the pK_a of I reinforce this conclusion. The enol form of cyclopentane-1,3-dione has a pK_a of 4.5.[18] Assuming 1% of the diketone at equilibrium, cyclopentane-1,3-dione would have a pK_a of 2.5. Reduction of the double bond in I would increase the K_a by three or four powers of ten, and this greater acidity may be due in part at least to the fact that structures like XIb and XIc do not contribute as much to the hybrid as they do in the dihydro case.[21]



a b c

XI

An analogous argument may be advanced to explain the greater reactivity of maleic anhydride as a

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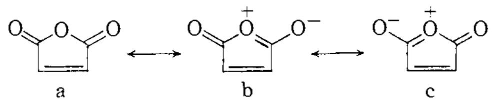
[18] J. H. Both, R. G. Wilkinson, S. Kurshner and J. H. Williams, This Journal, **75**, 1782 (1953).

[19] E. D. Bergmann in "Progress in Organic Chemistry," Vol. III, Academic Press, Inc., New York, N. Y., 1955, p. 117.

[20] Details of the n.m.r. spectrum, which is completely consistent with the structure, will be published in due course.

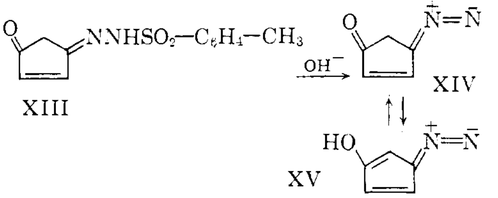
[21] This argument is tantamount to saying, in resonance terminology, that cyclopentadienone has a *negative resonance energy*, *i.e.*, that it is less stable than would be predicted on the basis of its Kekulé structure.

dienophile. It might have been expected that compound I would be the more reactive of the two in Diels–Alder reactions, for the reactivity of a dienophile is increased as the electron withdrawing power of the substituents are increased.[22] The ring oxygen would be expected to donate electrons to the carbonyl group, and so to decrease their electron-withdrawing power, *i.e.*, XIIb, c. The π-electron system in maleic anhydride is isoelectronic with that in the cyclopentenedione anion XI, and consequently it might be expected that structures XIIb and c would not contribute as much to the stability of maleic anhydride as they would to the stability of a normal anhydride. Therefore in forming an adduct maleic anhydride would be gaining back some resonance energy, and this could be an additional driving force for the reaction.[23] A similar explanation may be advanced to account for the abnormal reactivity of maleic anhydride toward radicals in copolymerization reactions.[24] It should not be inferred that we necessarily claim that this is the only possible explanation for the greater reactivity of maleic anhydride, but only that this sort of damping of resonance in completely unsaturated five-membered rings needs to be considered.



XII

One final reaction, or rather lack of reaction, needs to be considered. As mentioned earlier, we prepared the monotosylhydrazone of I and attempted to prepare from it the vinylogous diazoketone XIV by treatment with base, following the elegant method of Cava, *et al.*[25] This diazoketone was of interest because of the possibility of its enolizing to a derivative of diazocyclopentadiene (XV).



Compound XIII formed a salt with NaOH, but was recovered unchanged after prolonged boiling with aqueous NaOH. It appears probable that the added stability of the anion imparted by the increased conjugation may make the reaction too slow.

Acknowledgment.—We are indebted to B. Ponder, R. Thurn and G. Schenk for some of the experiments described in this paper, and to the Institute for Atomic Research, Ames, Iowa, for some of the infrared spectra. We wish to thank the Columbia–Southern Chemical Co. for a generous gift of cyclopentenediols. We thank Dr. E. Wenkert for interesting discussions and especially for information on elimination reactions of O-alkylamine oxides in advance of publications.

Experimental[26]

***cis*-3,5-Dibromocyclopentene.**—This dibromide was prepared in 20% yield by bromination of cyclopentadiene following the procedure of Young, *et al.*[6]

Alkylation of Pyridine-N-oxide.—To 30 g. (0.32 mole) of pyridine-N-oxide in 50 ml. of dry benzene was added, dropwise with stirring, 35.8 g. (0.16 mole) of *cis*-3,5-dibromocyclopentene in 50 ml. of dry benzene. The mixture was stirred for 4 hours at room temperature and the product removed by filtration, washed well with benzene, and dried. It was a white solid which melted with decomposition at 110°. The yield was 56 g. (84%).

Anal. Calcd. for $C_{15}H_{16}N_2O_2Br_2$: C, 43.27; H, 3.85; N, 6.73; Br, 38.5. Found: C, 42.04; H, 3.85; N, 6.67; Br, 38.3.

Base Cleavage of the O-Alkylpyridine.—To the solid O-alkylpyridine (100 g., 0.24 mole) was added dropwise with stirring a solution of KOH (27 g., 0.48 mole) in 300 ml. of water. The reaction flask was immersed in an ice-bath. The addition took one hour, and the resultant black solution was stirred an additional half-hour, and then continuously extracted with ether for two days. The ether extract was washed with dilute HCl to remove pyridine and then successively with 5% Na_2CO_3, water and saturated NaCl. The ether was carefully removed and the product sublimed. It melted at 96–98° and did not depress the melting point of an authentic sample of 1,8-diketo-4,7-methano-3a,4,7,7a-tetrahydroindene (VI). The yield was 2.6 g. (13%). Other runs gave varying amounts of VI, but never exceeding this yield. When a reaction was run in which only one molar equivalent of pyridine N-oxide was used, no product of any sort was obtained in either extraction.

***cis*-3,5-Diacetoxycyclopentene** was obtained in 75% yield from the dibromide by reaction with tetraethylammonium acetate in dry acetone according to the directions of Owen and Smith.[13]

***cis*-3,5-Cyclopentenediol.**—The unsaturated diacetate (38 g., 0.2 mole) was hydrolyzed by heating an alcoholic solution under reflux for 24 hours with BaO (128 g., 0.75 mole). The precipitated barium salts were removed by filtration and CO_2 was passed into the solution until no more $BaCO_3$ precipitated. Evaporation of the solvent and vacuum distillation gave the diol as a thick liquid, b.p. 120° (2 mm.), yield 14.6 g. (73%). It formed a bis-phenylurethan, m.p. 195–196°, lit.[14] m.p. 195–196°.

Cyclopentene-3,5-diols.—A mixture of cyclopentenediols, kindly furnished by the Columbia–Southern Chemical Co., was subjected to careful fractionation through a spinning brush column of approximately 20 theoretical plates. The 3,4-diol distilled below 90° (0.5 mm.) and the 3,5-diol could be obtained in about 50–60% yield, b.p. 90–95° (0.5 mm., $n^{25}{}_D$ 1.501. Periodic acid titration of the latter showed it to contain less than 5% of the 3,4-diol. The early fractions contained greater than 95% 3,4-diol, as determined similarly.

Cyclopentene-3,5-dione. (i) **Oxidation in Acetic Acid.**—To a cold solution of the 3,5-diol (8.7 g., 0.087 mole) in 15 ml. of 80% acetic acid was added, dropwise with stirring, 232 ml. of 3 *N* chromic acid in glacial acetic acid. The rate of addition was regulated so that the temperature of the reaction mixture remained below 0°. After addition was complete the mixture was allowed to stir overnight at room temperature. Most of the acetic acid was removed at room temperature under vacuum, the black residue was diluted with 400 ml. of water and extracted with 3 × 100 ml. of methylene chloride. After drying over anhydrous sodium sulfate the solvent was removed and the resulting oil placed in a sublimator. The crystalline dione slowly sublimed at

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[22] "Organic Reactions," Vol. IV, John Wiley and Sons, Inc., New York, N. Y., 1948, p. 60.

[23] If there is less resonance in maleic anhydride than usual for an anhydride, this should be reflected in the infrared spectrum of the molecule. It is not clear just what effect the double bond will exert on the spectrum, but the cyclopentadiene adduct of maleic anhydride has its carbonyl bonds at shorter wave length than does maleic anhydride, which is at least consistent with this suggestion.

[24] C. Walling, "Free Radicals in Solution," John Wiley and Sons, Inc., New York, N. Y., 1957, p. 118.

[25] M. P. Cava, R. L. Little and D. R. Napier, THIS JOURNAL, **80**, 2257 (1958).

[26] Melting and boiling points are uncorrected.

50° and 3 mm. Recrystallization from ether–pentane gave 4.6 g. (55% yield) of the diketone as a yellow solid with an irritating odor. The melting point was 37–38°.

Anal. Calcd. for $C_5H_4O_2$: C, 62.5; H, 4.17; mol. wt., 96. Found: C, 62.3; H, 4.0; mol. wt., 96.

Its colorless di-O-methyloxime melted at 116–117° after recrystallization from ethanol.

Anal. Calcd. for $C_7H_{10}N_2O_2$: C, 54.54; H, 6.54; N, 18.17. Found: C, 54.60; H, 6.23; N, 18.35.

(ii) **Oxidation in Acetone.**—To a cold stirred solution of the diol (20 g., 0.20 mole) in 200 ml. of acetone was added dropwise with stirring a solution of chromic anhydride (30 g., 0.3 mole) in a mixture of 60 ml. of concentrated sulfuric acid and 142 ml. of water. The reaction flask was surrounded by an ice-bath, and the addition regulated so that the temperature in the flask did not rise above 0°. After the addition was complete the reaction mixture was stirred an additional two hours at 0°, allowed to warm to room temperature, diluted with 400 ml. of water and extracted three times with 300 ml. of methylene chloride. The combined extracts were washed with 100 ml. of water, dried over anhydrous sodium sulfate, and the dione isolated as above. Yields are generally about 8 g. (42%), but despite the lower yield this procedure is more convenient than the oxidation in acetic acid.

Cyclopentane-1,3-dione.—To a vigorously stirred mixture of 5 g. of zinc dust in 25 ml. of glacial acetic acid was added dropwise cyclopentene-3,5-dione (0.50 g.) in 25 ml. of acetic acid. The addition took 45 minutes, during which time the flask was immersed in an oil-bath at 85°. The reaction mixture was cooled, filtered and the acetic acid removed at room temperature under vacuum. The residue was extracted in a Soxhlet apparatus with chloroform, the chloroform removed and cyclopentane-1,3-dione sublimed at 120° (4 mm.); yield 0.23 g. (45%) m.p. 149–150° (reported[18] 150–151°).

Catalytic Hydrogenation of Cyclopentene-3,5-dione.—The dione (1.0 g.) in 25 ml. of ethyl acetate was hydrogenated at room temperature and atmospheric pressure using Adams catalyst.[27] Absorption stopped after 2.7 molar equivalents of hydrogen had been used. The solution was filtered and the solvent removed. Titration of an aliquot of the oily product showed that not more than 2% of acidic material was present. The infrared spectrum showed a single carbonyl peak at 5.75 μ and an intense hydroxyl band. Gas chromatography showed the presence of two compounds in about equal amounts, one of which had the same retention time as did cyclopentanone. The 2,4-dinitrophenylhydrazone of the mixture was prepared and chromatographed. Roughly equal amounts of the 2,4-DNP of cyclopentanone (m.p. 142–143°) and of cyclopentenone (m.p. 166–167°) were isolated.

Monotosylhydrazone of Cyclopentene-3,5-dione.—To 500 mg. (0.52 mole) of the dione in 10 ml. of hot methanol was added 915 mg. (0.049 mole) of tosylhydrazine. The mixture was allowed to stand and then cooled to 0° and filtered. Recrystallization from 95% ethanol gave 1.15 g. (90% yield) of the monotosylhydrazone, m.p. 185–186° dec.

Anal. Calcd. for $C_{12}H_{12}O_3N_2S$: C, 54.54; H, 4.58; N, 10.60. Found: C, 54.45; H, 4.68; N, 10.9.

This tosylhydrazone was readily soluble in dilute NaOH. It could be recovered in 90% yield by acidification after heating at 100° with base. Although some coloring of the solution took place, no evidence for the presence of a diazo grouping could be found.

Cyclopentadiene Adduct.—The adduct could be prepared in quantitative yield by mixing equimolar amounts of the dione and cyclopentadiene in four times their volume of benzene and allowing the mixture to stand at room temperature. The adduct begins to precipitate in a very short time. After a few hours the solution was filtered and the filtrate recrystallized from a mixture of chloroform–carbon tetrachloride and sublimed at 120–130° (1 mm.). The adduct had a melting point of 169.5–170.5°, and appeared to be 100% enolic.

Anal. Calcd. for $C_{10}H_{10}O_2$: C, 74.1; H, 6.2. Found: C, 73.9; H, 6.05.

Anthracene Adduct.—The dione (3.42 g., 0.036 mole) and anthracene (6.35 g., 0.036 mole) were refluxed in 40 ml. of benzene for four days. The precipitated adduct was filtered, dissolved in NaOH and again filtered, and precipitated by acidification with dilute HCl. The adduct weighed 8.7 g. (89% yield), m.p. 302–305° dec.

Reaction of Cyclopentene-3,5-dione with Aqueous Base.—To 500 mg. of the dione in 5 ml. of water was added 53 ml. of 0.1 *N* NaOH. After stirring at room temperature for 20 minutes the brownish-red solution was passed through an Amberlite IR 120 ion-exchange column to remove sodium ions. The aqueous solution of the polymer was then evaporated to dryness leaving a tan, highly enolic powder which was insoluble in organic solvents.

Anal. Calcd. for $C_5H_4O_2 \cdot {}^2/_3H_2O$: C, 55.55; H, 4.97. Found: C, 55.44; H, 4.87.

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[27] An apparatus which is especially convenient for this hydrogenation, and for others in which a relatively large amount of hydrogen is absorbed (in this case 620 ml.), is described by P. R. Story and C. H. DePuy, in press.

[CONTRIBUTION FROM THE DEPARTMENT OF BIOLOGICAL SCIENCES, STANFORD RESEARCH INSTITUTE]

Potential Anticancer Agents.[1] XXII. The Conversion of Cyclopentene Oxide to Cyclopentene Sulfide

BY LEON GOODMAN AND B. R. BAKER

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Reaction of cyclopentene oxide (6-oxabicyclo[3.1.0]hexane) (Ia) with potassium thiocyanate led directly to cyclopentene sulfide (6-thiabicyclo[3.1.0]hexane) (Va) in 20% yield. On reaction of the epoxide with ammonium thiocyanate, an 11% yield of cyclopentene thiocyanohydrin (VI) was obtained, along with 3% of cyclopentene sulfide (Va). Treatment of *trans*-2-thiocyanatocyclopentyl methanesulfonate (VIII) with aqueous sodium hydroxide gave a 63% yield of cyclopentene sulfide (Va).

In a previous paper of this series,[2] a number of methods for the conversion of cyclopentene oxide to cyclopentene sulfide were reported which would proceed under conditions compatible with the chemistry of nucleosides. Additional methods have now been found and are the subject of this paper.

A number of sulfur-containing reagents cause the direct conversion of epoxides to episulfides,[3] alkali thiocyanates being the most frequently used. A mechanism for the thiocyanate reaction was advanced by Ettlinger[4] and given support by

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[1] This work was carried out under the auspices of the Cancer Chemotherapy National Service Center, National Cancer Institute, Contract No. SA-43-ph-1892. For the preceding paper of this series, *cf.* L. O. Ross, L. Goodman and B. R. Baker, *J. Org. Chem.*, **24**, in press (1959).

[2] L. Goodman, A. Benitez and B. R. Baker, THIS JOURNAL, **80**, 1680 (1958).

[3] C. C. Culvenor, W. Davies and W. E. Savige, *J. Chem. Soc.*, 4480 (1952).

[4] M. G. Ettlinger, THIS JOURNAL, **72**, 4792 (1950).