CYCLOBUTADIENE META - QUINONES

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CYCLOBUTADIENE META-QUINONES

by

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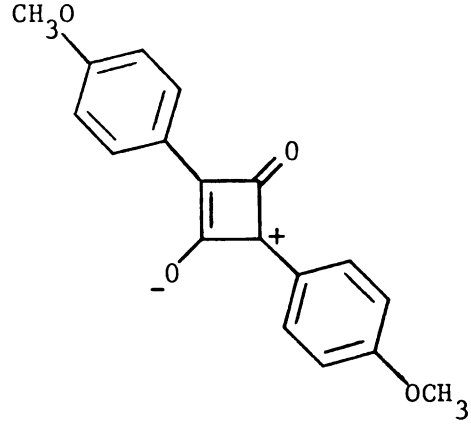
Abstract

Cyclobutadiene Meta-Quinones

by Anthony D. Wolf

Some approaches to the synthesis of several cyclobutadiene meta-quinones are considered. The synthesis of 2,4-di-p-methoxyphenylcyclobutadiene meta-quinone (XXVIII) is described and, a structure proof based on both physical and chemical evidence is presented.



XXVIII

ACKNOWLEDGEMENT

The author would like to express both his thanks and appreciation to Dr. Donald G. Farnum for his guidance and friendship throughout the course of this project.

to my parents

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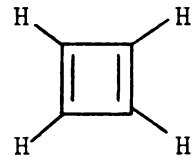
Introduction

During the past ten years intensive investigation into the synthesis and isolation of cyclobutadiene and its derivatives has been conducted. The challenge to chemists arose out of the corollary to the Hückel prediction that systems of 4n π electrons (n=0, 1, 2 etc., on a fully conjugated monocyclic π electron system) would possess reactivity on a par with or perhaps greater than their open chain analogues. This prediction seems to have been realized in the instance of cyclobutadiene (I) and its derivatives.[1]

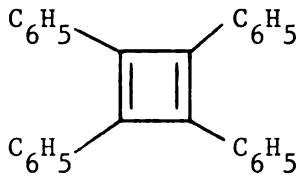


I

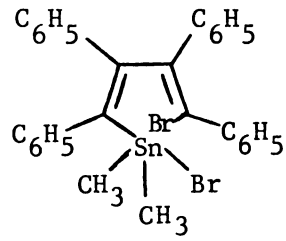
Cyclobutadiene itself would be expected to be more reactive than the open chain analogue 1,3-butadiene. This is reasonable since according to Hückel theory it should possess no special electronic stability, while at the same time, however, the molecule possesses considerable strain energy, as a result of constraining four sp^2 orbitals, which normally have bond angles of 120°, to a situation in which they have a strain of 30¼ per carbon.

Experiment has born out these expectations. Neither cyclobutadiene nor its derivatives has been amenable to synthesis with classical diene methods. Only with new synthetic methods could these systems be approached. Pettit and coworkers have suggested that cyclobutadiene is a highly reactive intermediate of finite lifetime.[2] More recently Freedman and Sandel have presented a detailed physical study, in which tetraphenylcyclobutadiene (II)

was postulated as an intermediate in the pyrolyses reactions of (4-bromo-1,2,3,4-tetraphenyl-cis,cis-1,3-butadienyl) dimethyltin bromide (III).[3]

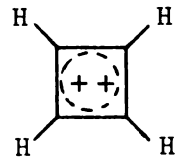


II



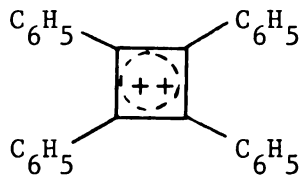
III

Also of interest is the dipositive ion cyclobutadiene dication (IV). This system possess the necessary complement of 2π electrons for a closed shell configuration and would therefore be expected to be aromatic.

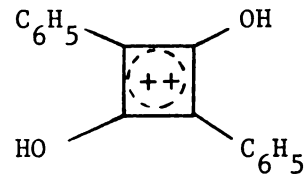


IV

Cyclobutadiene dication itself has not yet yielded to synthesis. However, the following derivatives, IV and VI have been reported by Freedman

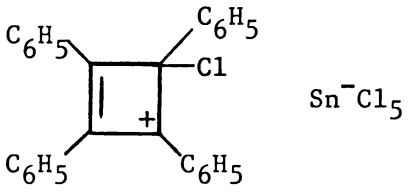


V



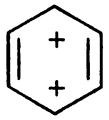
VI

and Farnum respectively.[4,5] The report on the synthesis of V,[4] has been shown to be in error. X-Ray studies show that rather than the hexachlorostannate salt of V, chlorotetraphenylcyclobutadienyl pentachlorostannate (VII) was produced.[6]



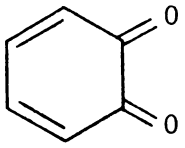
VII

As aromatic systems go, benzene is a pillar, being the most well known in the 6π electron class. As cyclobutadiene is to cyclobutadiene dication in structure, so benzene is to benzene dication VIII.

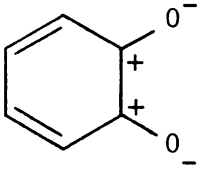


VIII

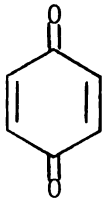
Benzene dication itself has not been made. This is understandable in view of the fact that there is a net loss of electronic stability in going from the aromatic benzene system, to the antiaromatic dication.[7] It is noteworthy and interesting in relation to benzene dication, that ortho-benzoquinone (IX) and para-benzoquinone (X) do exist and are stable, though reactive. One can write resonance contributors XI and XII for



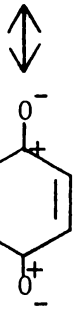
IX



XI

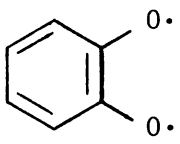


X

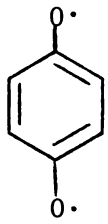


XII

structures IX and X, which involve the benzene dication. In view of the predicted instability of benzene dication, contributions from ionic resonance forms XI and XII to their respective quinones, should be small at best. However, resonance contributors XIII and SIV might be expected to be more important, since a full complement of six π electrons is maintained. Thus



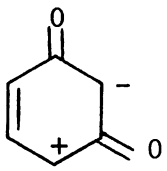
XIII



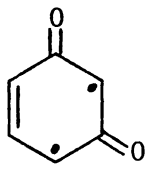
XIV

these quinones exhibit some of the stability associated with 6π electron systems, rather than the instability expected for 4π electron systems. The great facility with which these systems undergo free radical hydrogen atom addition indicates their tendency to go to an authentic 6π electron system.

Compared to ortho- and para-benzoquinones, the still unprepared isomer meta-benzoquinone is an anomaly. On attempting to write down its structure one becomes immediately aware of the uniqueness of this species in comparison to both its ortho and para isomers. Once can write either a dipolar or triplet diradical species such as XV or XVI as possible structures



XV

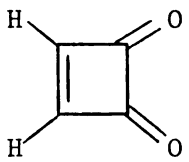


XVI

for this system. Consequently one can imagine that if formed, a meta-quinone might be reactive.

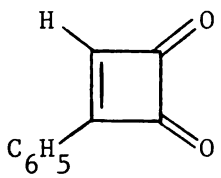
Cyclobutadiene like benzene, has its series of quinone isomers, fittingly entitled cyclobutadienoquinones. Two systems are possible, namely, cyclobutadiene ortho-quinone and cyclobutadiene meta-quinones.

Cyclobutadiene ortho-quinone (XVII), the parent member in the series of 1,2-cyclobutadienoquinones has not as yet been prepared.[1]

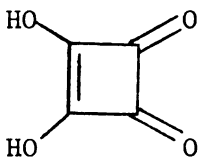


XVII

However several derivatives have been reported. The first member in the series to be reported was phenylcyclobutadienoquinone (XVIII),[8] while later members included the popular 3,4-dihydroxy-1,2-cyclobutadienoquinone or



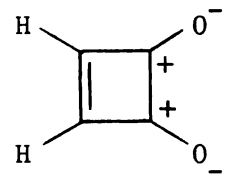
XVIII



XIX

"squaric acid" (XIX).[9]

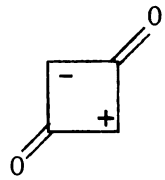
With benzoquinone it was thought that resonance forms XI and XII contributed negligibly to the stabilization of these systems since the π electron density operating over the ring would be reduced. The system would thus be destabilized relative to benzene. This same effect in cyclobutadiene ortho-quinones however, would only contribute to the system's stabilization by reducing the π electron density so that the system resembles the cyclobutadiene dication. Resonance structures such as XX,



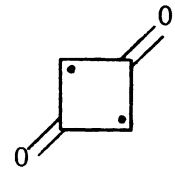
XX

which involve a dication, would then be expected to be much more important in cyclobutadiene ortho-quinones than in benzene ortho- and para-quinones.

Cyclobutadiene has a 1,3-quinone system, cyclobutadiene meta-quinone, which is analogous to benzene meta-quinone. This system must have either a singlet ground state as implied by dipolar resonance contributors such as XXI, or a triplet diradical ground state such as XXII. As in the case of meta-benzoquinone, it is not possible in terms of simple resonance theory



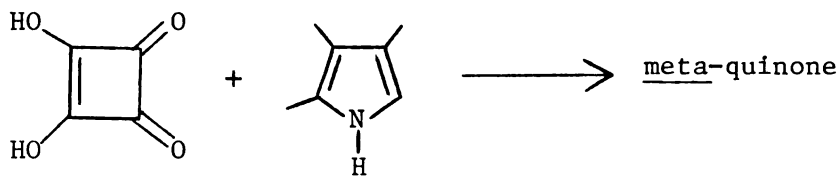
XXI



XXII

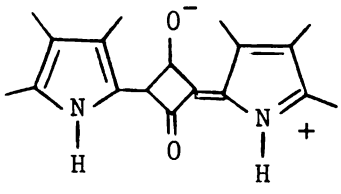
to predict which structure the molecule would actually have.

The first cyclobutadiene meta-quinones were reported in 1965 by several German groups. Treibs and Jacob reported that condensations of "squaric acid" with activated pyrroles gave rise to systems having the meta-quinone skeleton.[10] This paper was soon followed by several others,

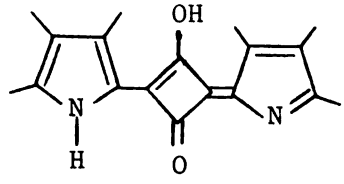


which added to a growing list of known meta-quinones.[11-14] No mention was made however, by any of the authors that these were indeed the first

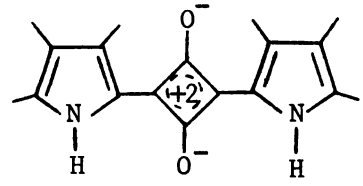
cyclobutadiene-meta-quinones. Furthermore, no rigorous structure determination to verify that the carbon skeleton was that of a meta-quinone was presented, so that several structures have been assigned to these systems. For example, Treibs and Jacob refer to the condensation products of pyrroles and squaric acid as having either structure XXIII or a tautomer XXIV.[10] Sprenger and Ziegenbein favor resonance contributor XXV.[11]



XXIII



XXIV



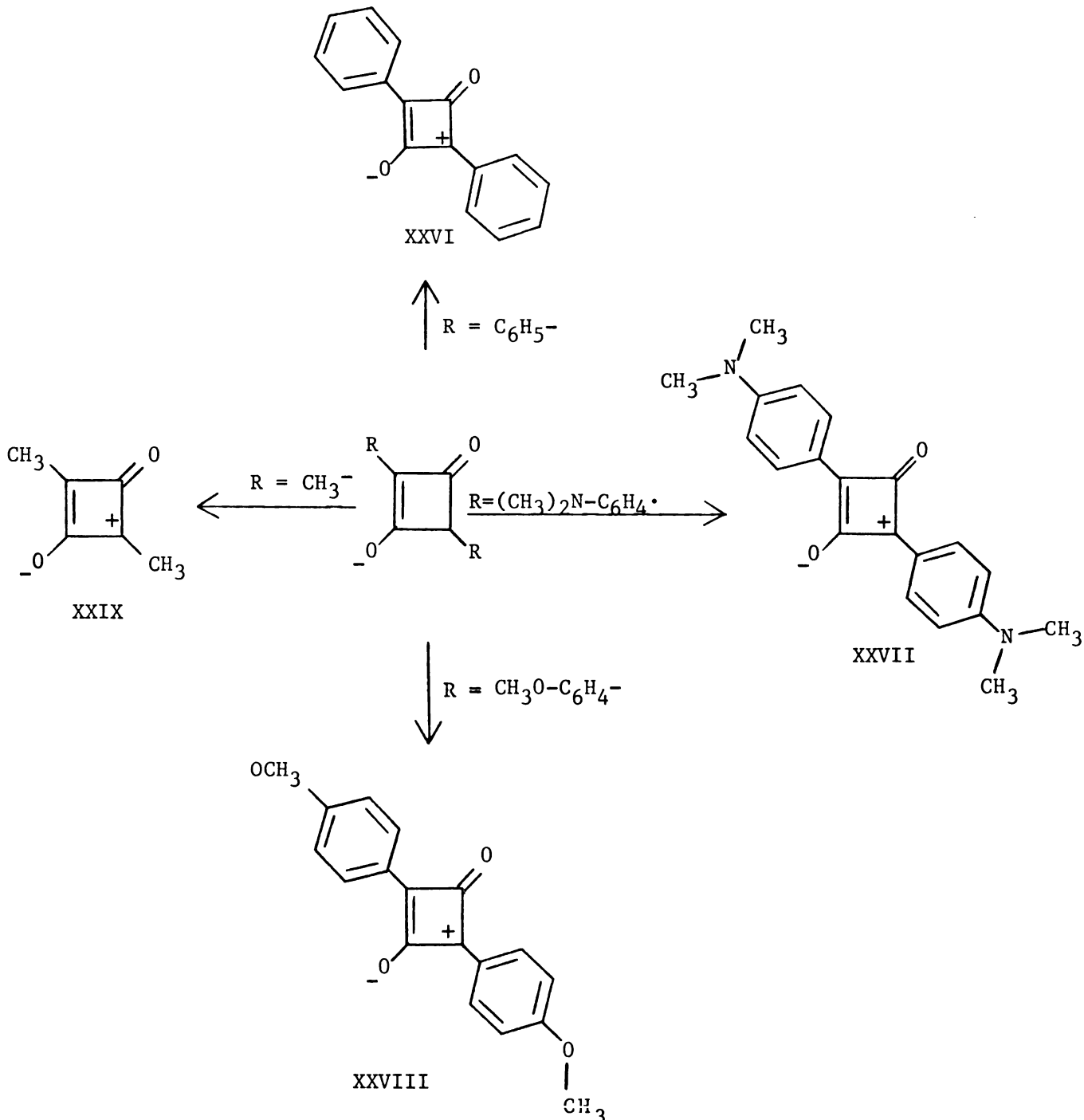
XXV

The object of this research was to prepare several cyclobutadiene meta-quinones and to establish their structure.

Results and Discussion

The goal of this project was the synthesis of the cyclobutadiene meta-quinones illustrated in Scheme 1. Each of these systems will be considered separately in Sections A, B, C and D.

Scheme 1

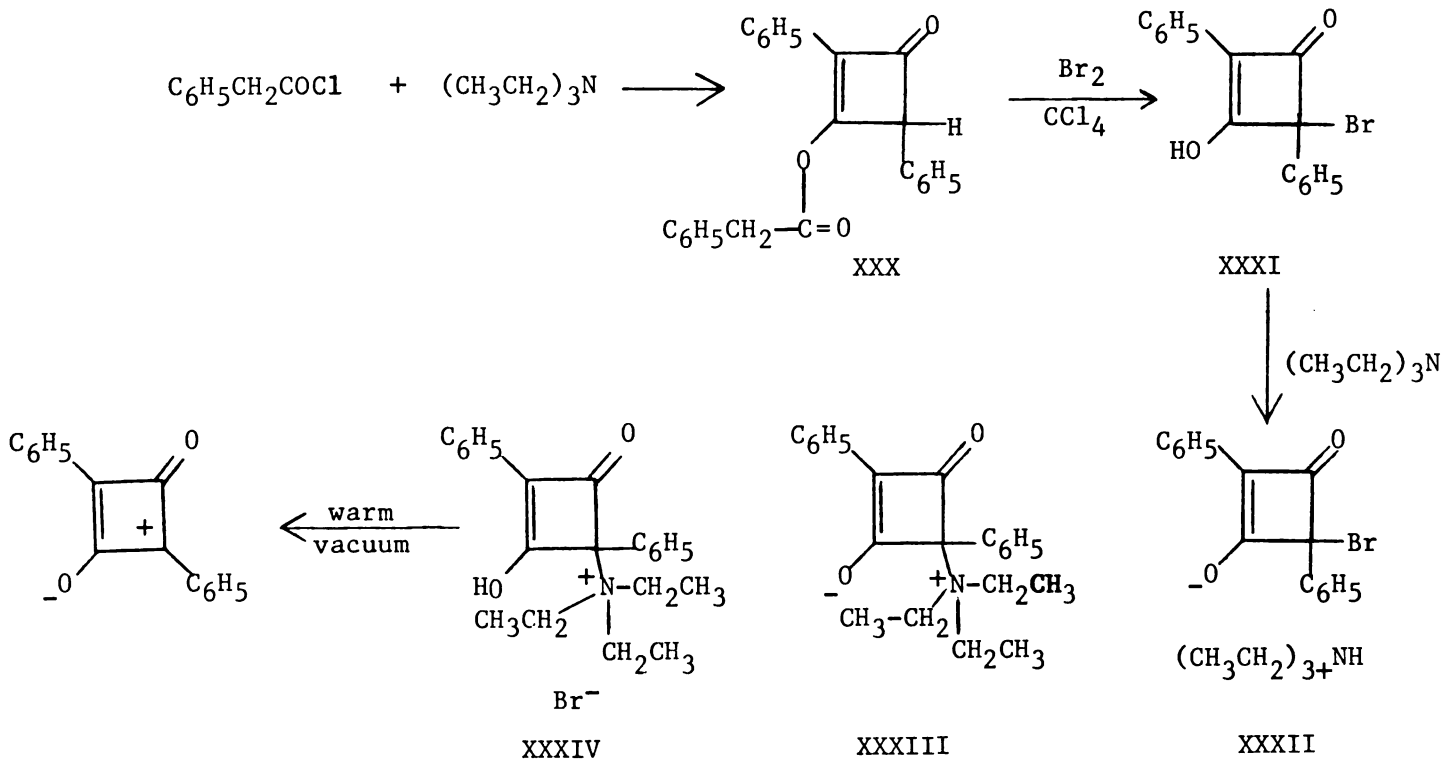


Section A

Approaches to the Synthesis of 2,4-diphenylcyclobutadiene meta-quinone (XXVI)

The route considered for the synthesis of meta-quinone XXVI was that shown in Path A. Condensation of phenylacetyl chloride with triethylamine

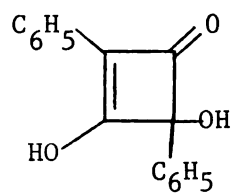
Path A



produced phenylketene trimer XXX.[15] This compound was then brominated with a solution of Br_2 in CCl_4, to give the reactive 2-bromo-2,4-diphenyl-3-hydroxycyclobutenone (XXXI), a white substance when pure, which turns red after a short time in air.[5] It was hoped that from bromoketone XXXI and triethylamine,

dipole XXXIII might be produced (salts XXXII and SSSIV also seemed to be likely products). From XXXIII gentle warming might lead to meta-quinone XXVI by loss of $(C_2H_5)_3N$.

On addition of $(CH_3CH_2)_3N$ to an ethereal solution of bromoketone XXXI a precipitate forms with the simultaneous appearance of a transient pink color. A comparison of the ir spectrum of the crude reaction product with those of the alcohol XXXV[5] and triethylammonium bromide showed that the



XXXV

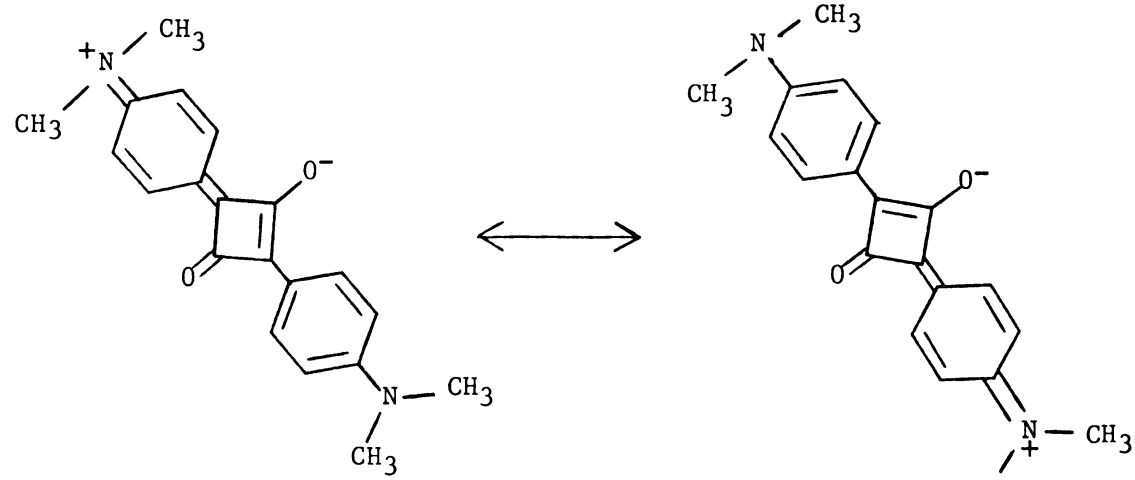
product was composed primarily of these two substances. Work up of the reaction mixture with non-nucleophilic solvents produced a 50% yield of alcohol and in general a greater than 50% yield of $(CH_3CH_2)_3NHBr$. No other products were isolated.

It was not possible in this attempt to isolate any of the salts XXXII, XXXIII and XXXIV. Only alcohol XXXV and triethylammonium bromide could be isolated.

Section B

Synthesis of the "Blue Product"

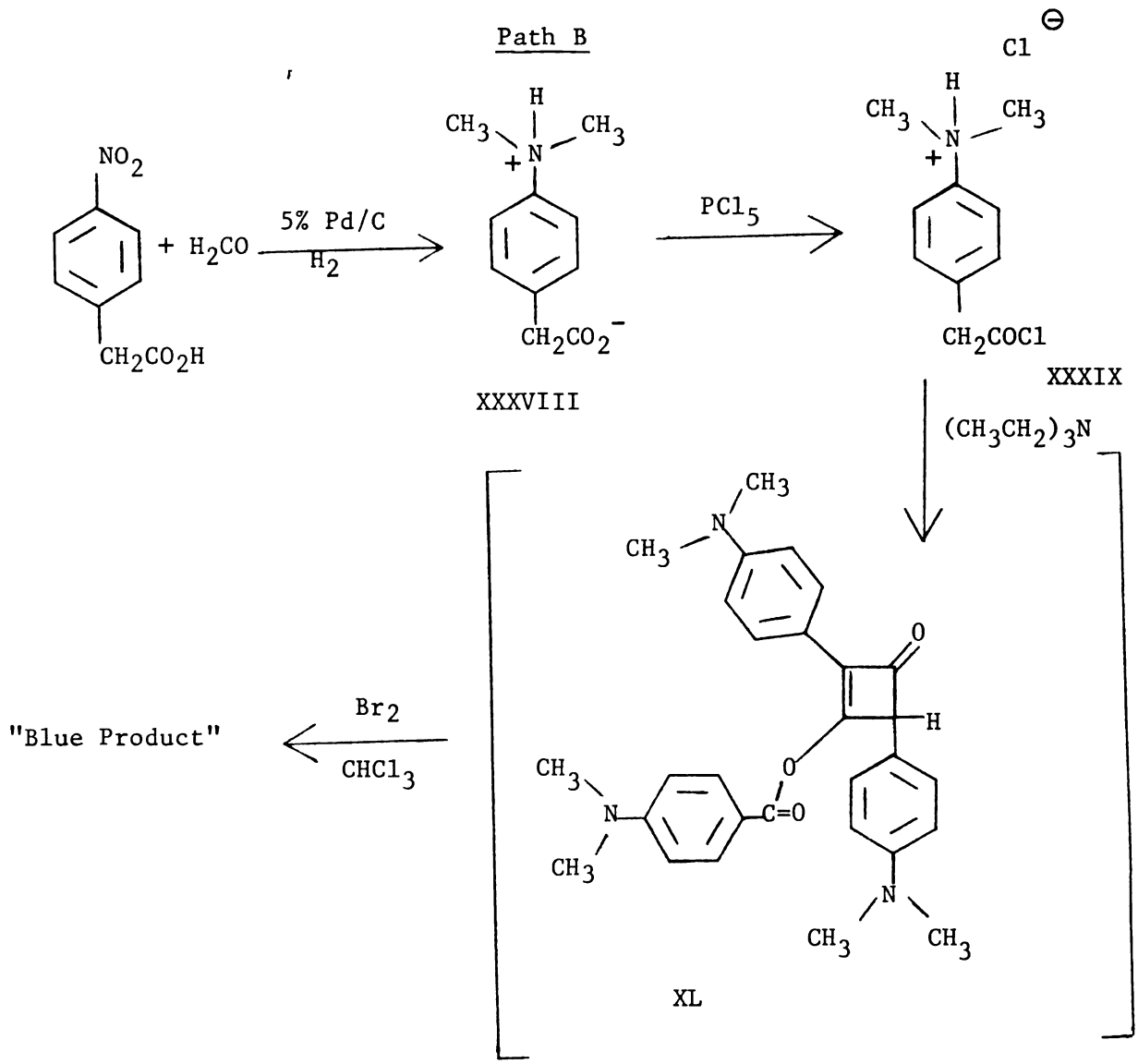
Meta-quinone XXVII with N,N-dimethyl substituents on the ring might be more stable than its counterpart XXVI, because of the possibility for delocalization of the positive charge to the nitrogens as shown in XXXVI and XXXVII. There are, of course, numerous other contributing forms. Furthermore, the report by Sprenger and Ziegenbein[13] that N,N-dimethylaniline



XXXVI XXXVII

and "squaric acid" give rise to a blue substance having structure XXVII, added more incentive to try the synthesis. An alternate route to the blue substance would offer more credence to the proposed structure.

The synthesis of the "Blue Product" involved the reaction sequence shown in Path B. Reaction of p-nitrophenylacetic acid with formaldehyde, under reducing conditions produced the amino acid XXXVIII.[16] Carbonyl absorption at 5.90 μ verified the presence of a carboxyl group in the molecule. The nmr spectrum exhibited singlets at τ 7.14 (area = 5.7) and 6.53 (area = 2),



which can be assigned to the N-methyls and benzylic protons, respectively. An A_2B_2 pattern centered at τ 3.18 ($\Delta\nu$ = .45 ppm, J = 8 cps, area = 4) demonstrated the presence of a p-disubstituted benzene. Absorption at τ -1.18 (area = 1) showed the presence of $-N\overset{+}{-}H$.

Treatment of amino acid XXXVIII with PCl_5, produced the acid chloride hydrochloride XXXIX.[17] Carbonyl absorption at 5.62 μ verified the presence of an acid halide. The nmr showed a pattern quite similar to that for the parent amino acid, namely, absorptions at τ 6.70 and 5.72 assigned

to the N-methyl and benzylic protons. An A_2B_2 pattern centered at τ 2.12 ($\Delta\nu$ = 43 ppm, J = 8 cps) was again characteristic of p-disubstituted benzene. XXXIX was not further purified, but was used directly in the condensation reaction with $(CH_3CH_2)_3N$ in ether. No product corresponding to trimer XL could be isolated. However on treatment of a chloroform solution of the ether extract with Br_2 in $CHCl_3$, a small amount of a black powder resulted. This powder partially dissolved in dimethyl sulfoxide, to leave a residue of about 1 mg. of a blue solid with melting point 290 - 305° (d).

The uv visible absorption spectrum was superimposable upon the spectrum obtained for the blue substance produced by condensation between N,N-dimethylaniline and "squaric acid".[13] The following absorptions were obtained for the "Blue Product". The strong absorption in the visible

$\lambda_{max}^{CHCl_3}$	ε	$\lambda_{max}^{CHCl_3/CF_3CO_2H}$	ε
623	3.48×10^5	607	4340
416	556	527	3.60×10^4
392	2840	496	6.14×10^4
368	3210	475	5.46×10^4
314	2220		

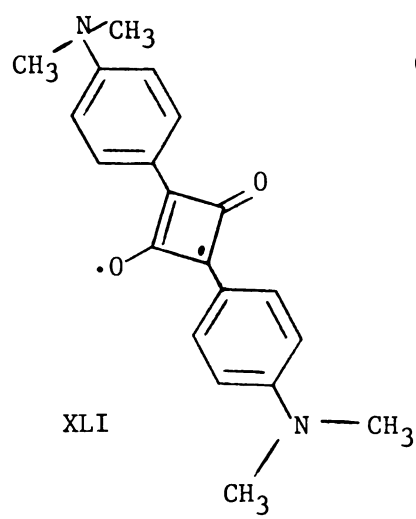
indicates a highly conjugated system. The large extinction coefficient seems to indicate a very facile $\pi \rightarrow \pi^*$ transition in the molecule. Ultraviolet absorption in strong acid solution causes a shift to shorter wavelengths and a very marked decrease in the extinction coefficient for the long wavelength absorption.

The nmr spectrum of the "Blue Product" in CF_3CO_2H was very simple, demanding a high degree of symmetry for a substance of molecular formula for $C_{20}H_{20}O_2N_2$. A singlet at τ 6.37 (area = 6) is reasonable for a

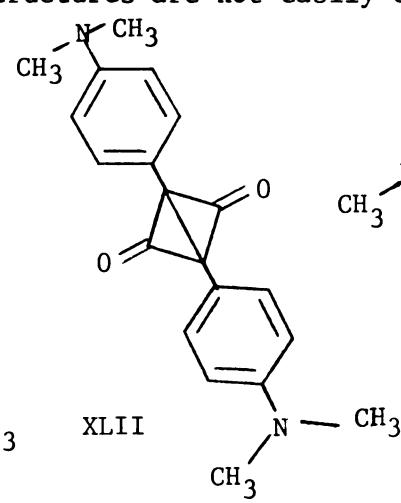
dimethylamino group in the molecule. An A_2B_2 pattern centered at τ 2.91 ($\Delta\nu$ = .83 ppm, J = 10 cps, area = 3.4) indicates again the presence of a p-disubstituted benzene. The low field position of the A_2B_2 pattern seems to indicate the presence of a deshielding influence operating in the molecule when compared to XXXVIII and XXXIX which have A_2B_2 patterns at higher field.

The ir spectrum of the "Blue Product" is striking in that so few bands are present. Again, such a simple spectrum seems to indicate a substance having a high degree of symmetry. The presence of a highly conjugated carbonyl group is suggested by the absorption at 6.32 μ with a shoulder at 6.2 μ and the absence of shorter wavelength carbonyl absorption.

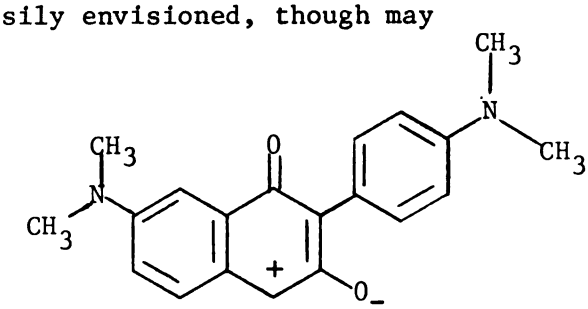
Several structures compatible with a molecular formula $C_{20}H_{20}N_2O_2$ can be written. In addition to XXVII, these include XLI, XLII, XLIII and XLIV. Other reasonable structures are not easily envisioned, though may



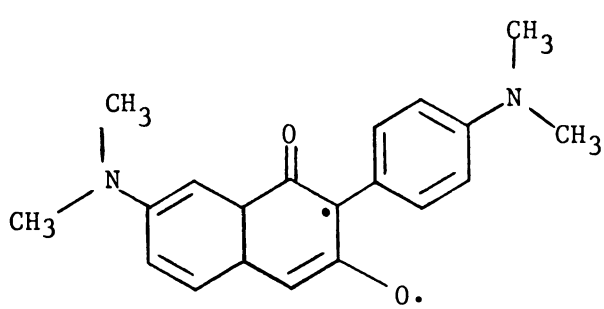
XLI



XLII

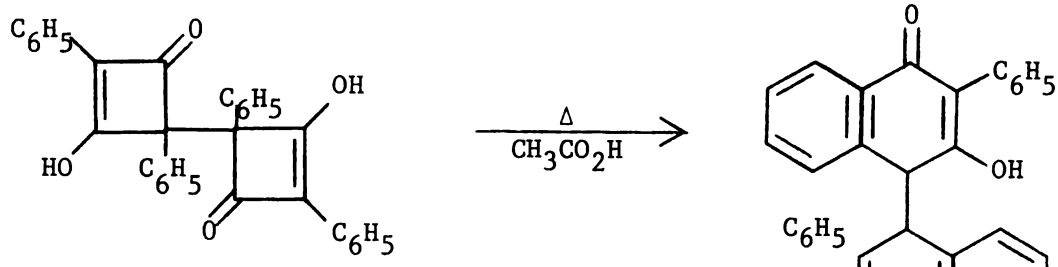


XLIII



XLIV

exist. There is some evidence for structures similar to XLIII and XLIV arising from cyclobutadienones in unpublished work of Farnum and Hess.[18] Recrystallization of a substance thought to have structure SLV leads to a new material, the evidence suggesting a structure such as XLVI.



XLV XLVI

On the basis of the nmr data structures such as XLIII and XLIV can be ruled out. These structures should give an nmr spectrum exhibiting two different dimethylamino groups and a complicated pattern in the aromatic region.

On the basis of uv data, structure XLII can be ruled out as a possibility. There is no reason to expect an absorption in the region of 623 mμ. Furthermore cyclopropanones should have absorption in the ir at about 5.6 μ.

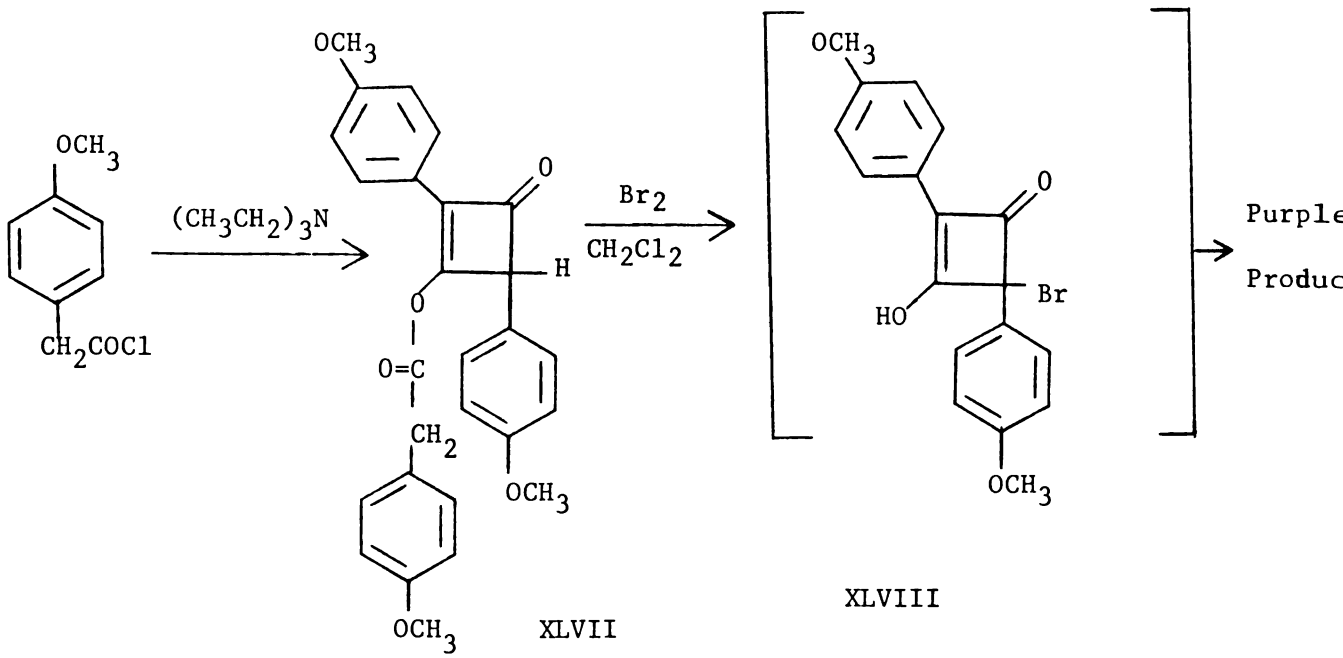
A structure which cannot be ruled out on the basis of the available evidence is XLI. And this possibility will be considered further in Section C. The structural question here is whether the system has a singlet ground state as implied by dipole XXVII or a triplet diradical ground state, as implied by XLI.

Section C

Synthesis of the "Purple Product"

Unpublished work of Farnum and Webster,[19] has shown that a purple substance possibly having the structure of meta-quinone XXVIII arises as indicated in Path C. Reaction of p-methoxyphenylacetyl chloride

Path C



with $(CH_3CH_2)_3N$ produces p-methoxyphenylketene trimer (XLVII). This trimer unlike its analogue in the phenyl series XXX, upon treatment with Br_2 in CH_2Cl_2 produces instead of the expected bromoketone XLVIII, a purple substance which will be referred to as the "Purple Product".[19] Crystallization from acetonitrile-benzonitrile produces beautiful delicate purple needles.

Analysis of the material was consistent with the formula $C_{18}H_{14}O_4$ and its spectral properties were very similar to those of the "Blue Product". Electronic spectra are indicative of a species having a highly conjugated

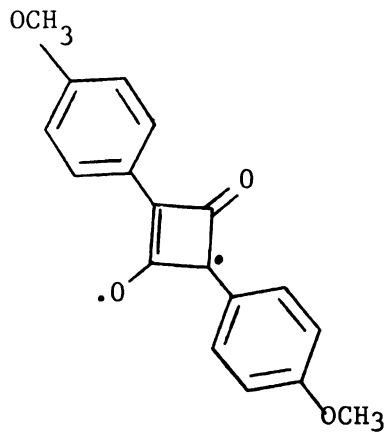
π-electron system undergoing a facile π-π* transition as shown by the magnitude of the extinction coefficients.

$\lambda_{max}^{CH_2Cl_2}$ (mμ)	ε	$\lambda_{max}^{CH_2Cl_2/CF_3CO_2H}$	ε
536	1.41×10^5	529	1.58×10^5
500	4.15×10^4		
348	9.73×10^3		

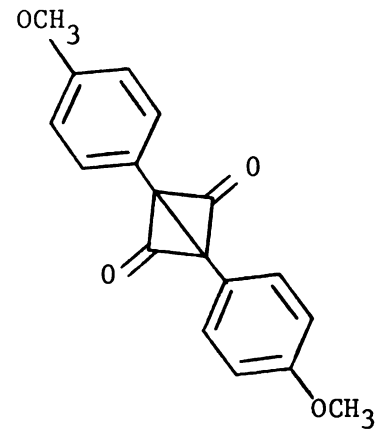
The rather simple ir spectrum indicates that the substance might be highly symmetrical. The 6.1 μ and 6.3 μ bands with no carbonyl absorption less than 6 μ, are characteristic of a highly conjugated ketone.

The substance gives a beautiful nmr spectrum in deuterochloroform-trifluoroacetic acid, quite simple in appearance. A sharp singlet at τ 5.97 (area = 3) is characteristic of a methoxy grouping in the molecule. An A_2B_2 pattern centered at τ 2.16 ($\Delta\nu$ = 1.35 ppm, J = 9 cps, area = 4.1) is characteristic of a p-disubstituted benzene, in which a deshielding influence must be causing the low field resonance of the aromatic protons.

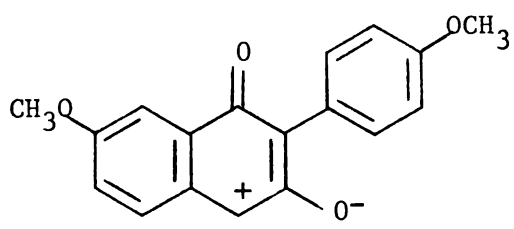
Several structures can be written for the "Purple Product", which are analogous to those written for the "Blue Product", that might arise from the bromination of trimer XLVII, and are compatible with the formula $C_{18}H_{18}O_4$. These include XXVIII and XLIX - LII. Again structures such as LI and LII



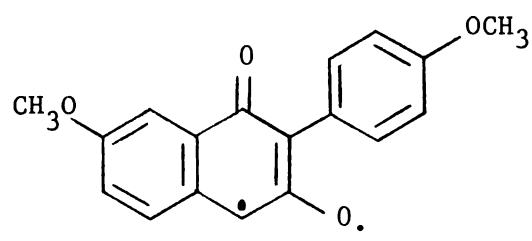
XLIX



L



LI

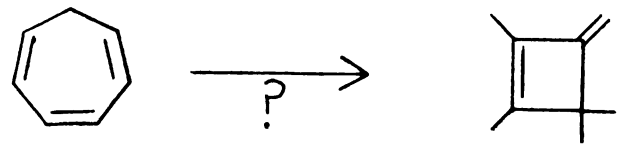


LII

can be ruled out on the basis of nmr evidence. The simple spectrum observed would not be predicted for these structures. The bicyclobutanedione L, is ruled out by both the electronic and ir spectra. The molecule does not possess enough conjugation to expect a band at 536 mμ in the electronic spectrum. Furthermore 6.1 and 6.3 μ are too long wavelength to be a cyclopropanone.

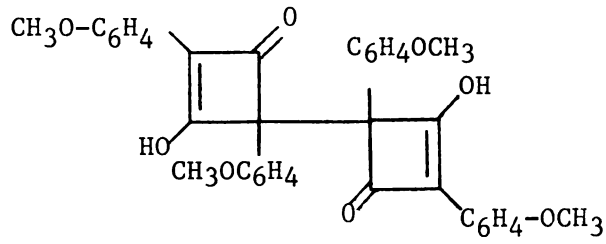
Only two structures need to be considered further namely XXVIII and XLIX. On the basis of an esr spectrum determined by Dr. D. H. Geske at Cornell University the diradical XLIX can be eliminated since the "Purple Product" did not give rise to an esr signal.

Although at this point all the physical data available pointed to XXVIII as the structure for the "Purple Product", it was considered desirable to obtain some chemical evidence for the presence of the four-membered ring. On this basis, reduction of the "Purple Product" with tropylidene might give rise to dienone LIII.[15] This would clearly demonstrate that the carbon



skeleton had remained intact in the conversion of trimer XLVII to the "Purple Product". Treatment of the "Purple Product" with topylidene in acetic acid, acetic anhydride-fluoroboric acid mixture, after two hours, produced a white solid on recrystallization from ethyl acetate.

Comparison of the data for the white solid and the dione clearly reveals that they are different species. A possible explanation for the formation of the white solid involves a "dimerization" to give a product having structure LIV. This structure would account for the observed spectra.

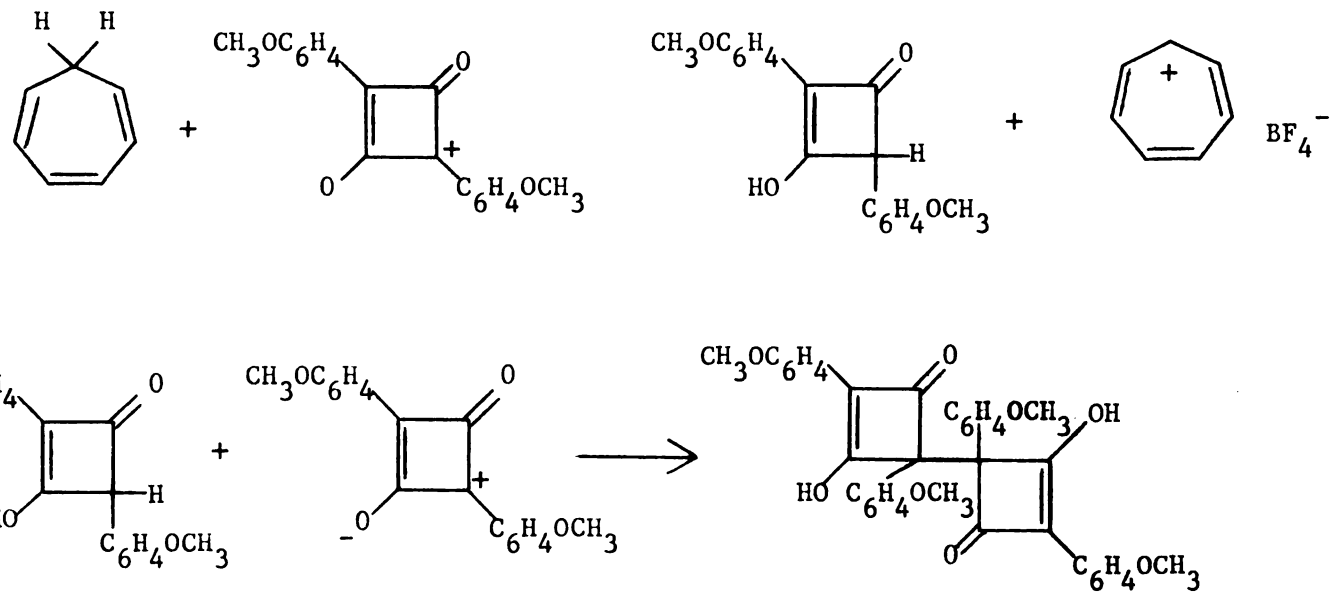


LIV

The nmr spectrum in deuterochloroform and trifluoroacetic acid exhibited two distinct sharp signals at τ 6.20 and 6.17 (total area = 6) characteristic of two different methoxy groups and two distinct A_2B_2 patterns in the aromatic region at τ 2.99 ($\Delta\nu$ = 60 ppm, J = 9 cps) and 2.80 ($\Delta\nu$ = .63 ppm, J = 9 cps), characteristic of two different p-disubstituted benzenes. The ir spectrum with peaks at 2.90 - 5.0 μ (br, w), 5.75 μ (s) and 6.20 μ (s), is compatible with the hydroxycyclobutenone system. Furthermore the suggestion of dimer formation seems reasonable on the basis of the evidence for a similar dimer XLV, in the phenyl series, whose ir spectrum gave similar absorption at 5.80 μ (s) and 6.18 μ (s). It is also interesting that the "Purple Product"

is reformed in 40% conversion from the white solid after ten hours in chloroform-trifluoroacetic acid, as evidenced by the A_2B_2 pattern at τ 2.24 ($\Delta\nu$ = 1.38 ppm, J = 9 cps) in the nmr spectrum.

The dimer formation can be envisioned in the following way.



If a dimer is formed by the route described above, then a reaction between the dione LIII and "Purple Product" in the absence of topylidene should also give rise to the dimer. And in fact when the dione and Purple Product are mixed together in acetic acid, acetic anhydride and fluoroboric acid, a solid is formed, which on recrystallization from ethyl acetate gives a white solid whose ir and nmr spectra are identical to those of the white solid arising from the tropylidene experiment. Neither the dione nor the "Purple Product" alone gave the dimer. On this basis then it is concluded that a dimer has formed in these reactions and has the structure LIV. Furthermore since the "Purple Product" by itself, gives rise to the same substance that arises from the "Purple Product" and another substance having the cyclobutadienone skeleton, then the "Purple Product" must also have the cyclobutadienone

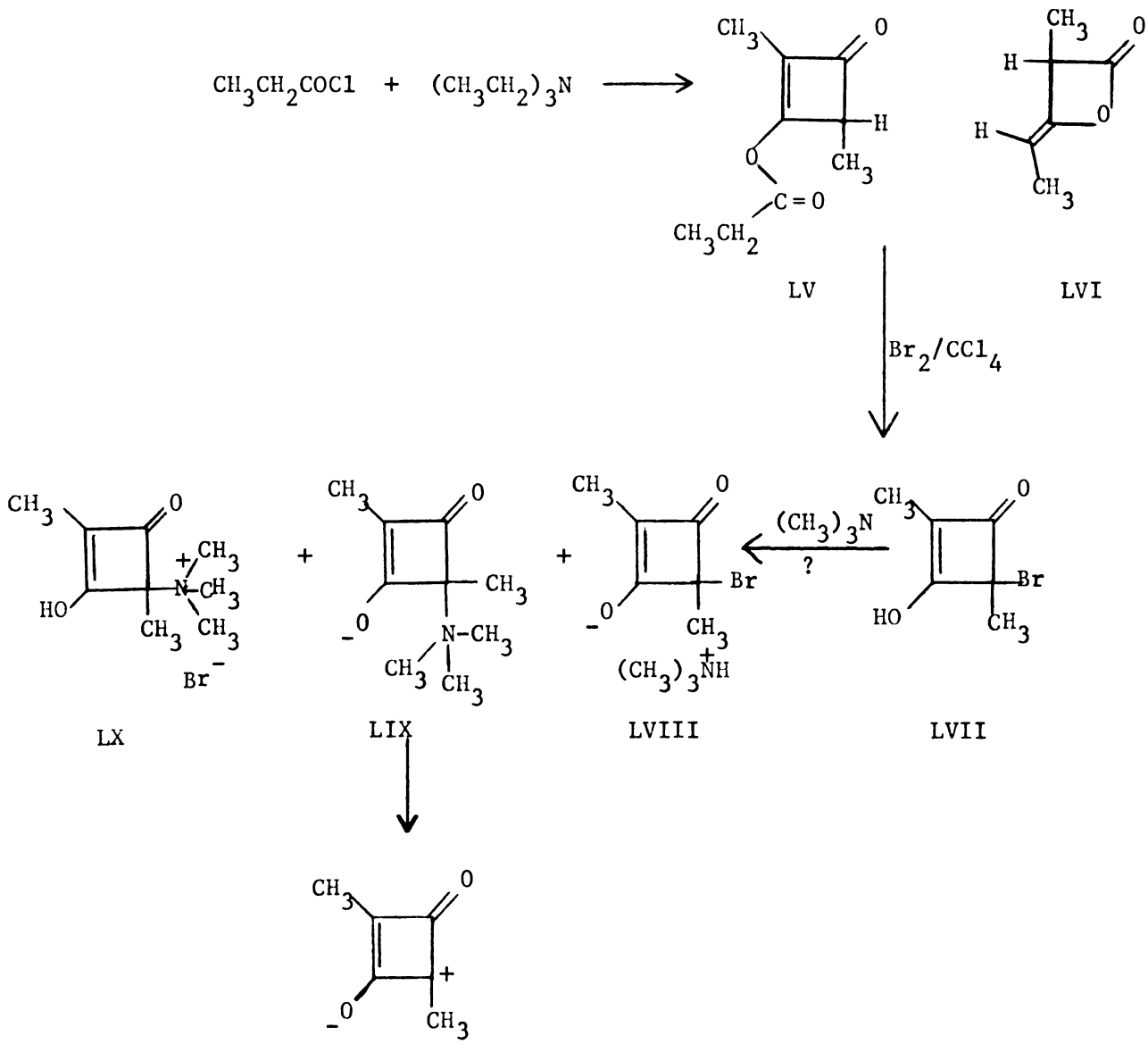
skeleton. Therefore, on the basis of a chemical structure proof and on the basis of the physical data presented, it is concluded that the "Purple Product" is 2,4-di-p-methoxyphenyl-cyclobutadiene-meta-quinone.

Section D

Approaches to the Synthesis of 2,4-dimethylcyclobutadiene meta-quinone (XXIX).

An attempt to synthesize meta-quinone XXIX is discussed in this section. The synthetic route followed was similar to that employed in Section A. And is illustrated in Path D.

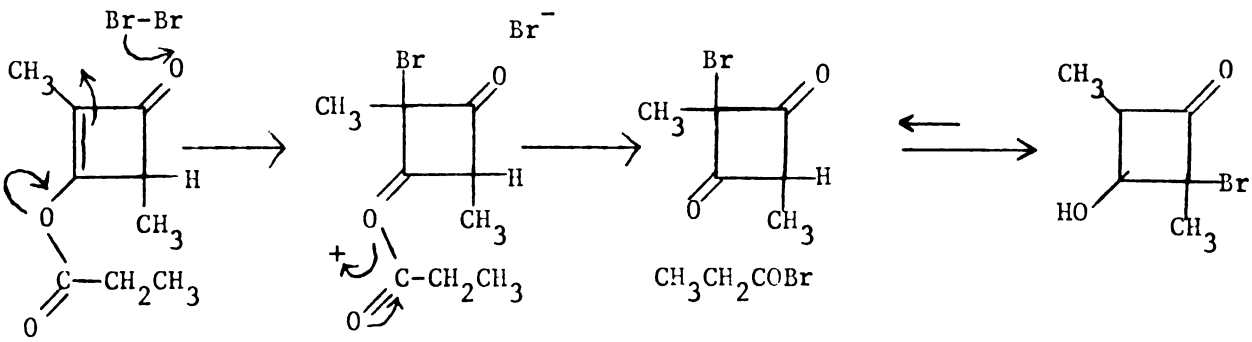
Path D



Reaction of propionyl chloride with $(CH_3CH_2)_3N$ in anhydrous ether produced an orange oil after workup from $(CH_3CH_2)_3NHCl$ and the solvent. The mixture which was composed primarily of methylketene trimer LV and β-lactone methylketene dimer[15] LVI, was not further purified. Instead the crude reaction product was diluted with carbon tetrachloride and treated dropwise with a solution of bromine in the same solvent, according to the method developed by Farnum and Webster.[19] A white precipitate formed which was recrystallized from a mixture of ethyl acetate in benzene. The white solid 2-bromo-2,4-dimethylcyclobutenone was identical by nmr and ir to the material reported.[20]

The transformation involving the conversion of trimer LV to bromoketone LVII is analogous to that conversion in the phenyl series. It can be envisioned mechanistically as shown in Scheme 2.

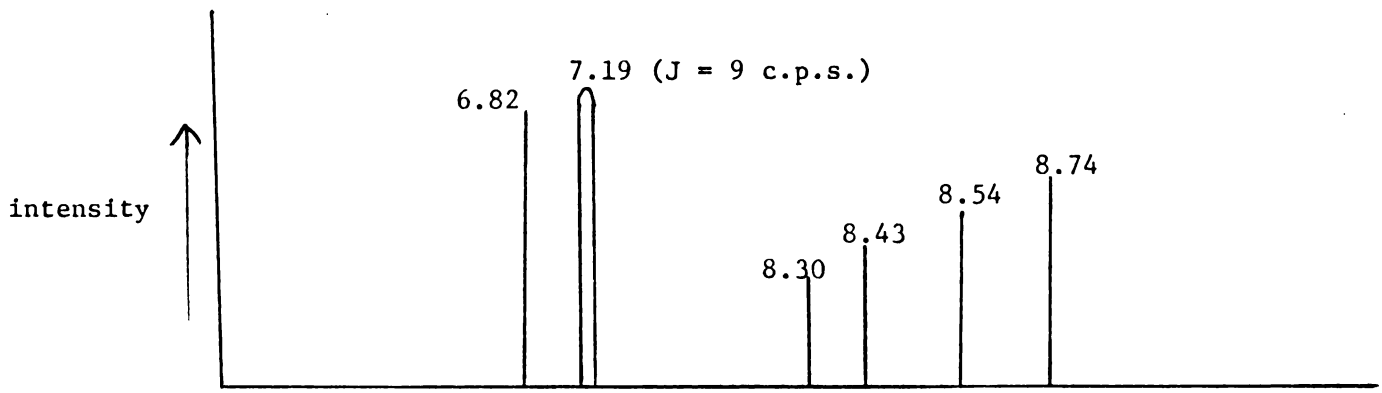
Scheme 2



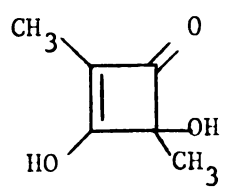
It was hoped as shown in Path D, that treatment of LVII with $(CH_3)_3N$ would produce the dipole LIX, (though LVIII and LX represent possible products from this reaction). Isolation of LIX might lead to the desired meta-quinone, XXIX, by loss of $(CH_3)_3N$ with gentle warming in a vacuum.

In a typical reaction a sample of bromoketone LVII was placed in a solvent trap cooled to -78°C. Trimethylamine was condensed in the trap until a estimated 10-15 equivalents was present. The suspension was then stirred using a magnetic stirring bar or vibro-mixer. The cooling bath was removed and the sample was stirred until all the $(CH_3)_3N$ had evaporated and only a powder remained. The nmr of the crude reaction mixture in d_6-dimethyl sulfoxide produced the spectrum shown in Figure 1.

Figure 1



The signals at τ 8.74 and 8.54 are assigned to the alcohol LXI[20] produced on solvolysis of bromoketone LVII. Addition of an authentic sample of alcohol to the reaction product served to increase these signals. Addition of bromide to the reaction product, produced two new signals at τ 8.48 and



LXI

8.33. With time these signals decreased and disappeared while those assigned to the alcohol increased. Thus the bromoketone LVII is readily hydrolyzed under the nmr conditions to the alcohol LXI.

Addition of a sample of $(CH_3)_3N^+H$ (from $(CH_3)_3NHCl$) to the reaction product increased the intensity of the doublet centered at τ 7.19, J = 9 cps. A coublet for $(CH_3)_3N^+H$ is consistent with the spectrum reported for this ion at low pH values.[21]

Yet still remaining to be explained is the product (s) giving rise to absorption at τ 8.43, 8.30 ppm (total area = 6) and 6.82 (area = 7.5). Possible structures which come to mind for the species giving rise to these nmr signals include LIX and the desired zwitterion LX. There are inconsistencies with either of these products, since one might imagine that these species would also hydrolyze since bromoketone **LVII** was so readily hydrolyzed. In fact addition of a drop of H_2O to the nmr sample does not noticeably alter the character of the unidentified signals.

Nothing further can be said about the identity of the species giving rise to the nmr signals. Isolation of the products has not as yet been feasible.

SUMMARY

The ultimate goal of this research - namely, the synthesis and structure proof of meta-quinones XXVI, XXVII, XXVIII and XXIX - was achieved only in part. This was in the case of 2,4-di-p-methoxyphenylcyclobutadiene meta-quinone XXVIII and perhaps in the case of the dimethylamine analogue. 2,4-Dimethylcyclobutadiene meta-quinone was not synthesized. The presence of an unidentified material arising in the synthetic route was demonstrated. The attempted synthesis of XXVI from bromoketone XXXI was not successful, but led to hydrolysis to form the alcohol XXXV. A transient pink color was observed in the reaction between bromoketone XXXI and triethylamine, though the species giving rise to this color was not identified.

In the near future, an X-ray study to establish the bond lengths and bond angles and perhaps even the electron density map in 2,4-di-p-methoxyphenylcyclobutadiene meta-quinone will be undertaken.

EXPERIMENTAL

Preparation of 2,4-diphenyl-3-phenylacetoxycyclobutenone XXX[15]

In a 3-l, three necked round bottomed flask equipped with a Friederichs condenser, a mechanically driven stirrer with a teflon paddle and a 500 ml. separatory funnel (equipped with a drying tube) was added 500 ml. of anhydrous ether and 53.3 g (.345 moles) of phenylacetyl chloride. To the refluxing solution was added a 500 ml. solution of 34.5 g (.342 moles) of triethylamine in anhydrous ether, over a period of 5 hours. The mixture was stirred at reflux for an additional 2 hours.

The reaction mixture was filtered warm to remove the precipitated triethylammonium chloride. Immediately on cooling, the light greenish filtrate began to precipitate tiny platelets of the desired product. The precipitated product was filtered and the filtrate was concentrated to about half by evaporation at room temperature with a roto-evaporator. On cooling precipitation produced more of the desired product. The concentration precipitation process was repeated again to give a third crop of crystals. The total yield of crude product was 85%. The product was not further purified at this stage but carried on to the next stage. If desired the product can be recrystallized from boiling ether. Yields in the reaction are variable.

ir λ_{max}^{nujol} 5.6 μ(s), 5.72 μ(s), 6.1 μ(s), 6.25.

nmr (deuterochloroform) τ 6.17 (singlet, area = 2), 4.70 (singlet, area=1) and 2.03 - 2.78 (complex multiplet, area = 15).

The spectroscopic data correspond with those reported by Farnum, et. al.[15]

Conversion of XXX to 2-bromo-2,4-diphenyl-3-hydroxycyclobutenone (XXXI).[19]

A stirred solution of 13.0 g (.038 moles) (XXX) in carbon tetrachloride was treated with a solution of 6.1 g (.038 moles) of bromine in the same solvent. A white precipitate formed which was filtered with a suction funnel and washed with benzene. Yield of crude bromide was 9.7 g (83.7%).

ir λ_{max}^{Nujol} 2.9-4.5 μ (br), 5.75 μ (m), 6.1-6.5 μ (br,m); (lit.)[5] λ_{max}^{Nujol} 5.71 μ.

Conversion of XXXI to 2,3-dihydroxy-2,4-diphenylcyclobutenone (XXXV).[5]

A sample of bromoketone XXXI was added to a 5% sodium bicarbonate solution. Upon acidification with 1N hydrochloric acid a white solid formed which was filtered and dried in a vacuum desiccator.

ir λ_{max}^{Nujol} 2.9-5.0 μ (br, w), 5 75 μ (s), 6.3 μ (w), 8.70 μ (m); (lit.)[5] λ_{max}^{Nujol} 3.0 μ, 5.82 μ.

Reaction of XXXI with Triethylamine. Triethylamine was distilled from and stored over potassium hydroxide pellets for use in the reaction. Diethyl ether of reagent grade quality was distilled over lithium aluminum hydride, directly into the reaction vessel. All glassware was baked dry at 150°C. for several hours before use. The reaction mixture was kept under an atmosphere of helium.

In one such reaction 40 ml. of ether were distilled into a 100 ml. 3-necked flask previously swept with helium gas. To this was added .669 g. (2.02 mmoles) of recrystallized bromide XXXI. To the magnetically stirred ether solution was added dropwise .280 ml. (2.02 mmoles) of triethylamine with a syringe. The solution was bright orange after addition of the first drop of amine, but gradually turned yellow.

Workup consisted of filtration of the solid from mother liquor. Evaporation of ether produced a small amount of gummy oil, which had a broad ir band at 5.75μ, but no other distinguishing features. Further workup did not achieve isolation of any pure compounds. The solid filter cake isolated had an ir spectrum which exhibited all the peaks of a composite of the ir spectra of alcohol XXXV and triethylammonium bromide and no others. Washing of the solid with methylene chloride removed the triethylammonium hydrobromide. Evaporation of the solvent produced .225 g. The remaining filter cake (.230 g) had an ir spectrum identical to that of alcohol XXXV.

Preparation of p-N,N-dimethylaminophenylacetic acid (XXXVIII).[16] In a 500 ml. Parr pressure bottle was placed 18.1 g (.1 mole) of p-nitrophenylacetic acid. To this was added 150 ml. of glacial acetic acid, 25 ml. of formalin and .20 g of 5% Pd/C. The mixture was hydrogenated in a Parr hydrogenation apparatus for about 3 hours, or until the theoretical uptake of hydrogen had occurred.

The hydrogenated product was filtered and the filtrate evaporated until a white solid remained. The crude product has the odor of formaldehyde and is probably some polymeric form of the material. The product forms in almost quantitative yield, but recrystallization from 95% ethanol cuts the yield sharply to 37.8% (6.8 g).

ir λ_{max}^{Nujol} 3.0-5.0μ (br,w), 5.9μ (s), 6.18μ (m), 6.56μ (m), 6.82μ (s).

nmr (deuterochloroform) τ 7.14 (area = 5.7), 6.53 (area = 2) 3.18 (A_2B_2 pattern, $\Delta\nu$ = .45 ppm, area = 4) and -1.18 (area = 1).

Conversion of XXXVIII to p-N,N-dimethylaminophenylacetyl chloride hydrochloride XXXIX.[7] In a 500 ml. bottle was placed 7.2 g (.04 moles) of XXXVIII and 200 ml. of carbon tetrachloride. To this was added 16.7 g (.08 mm) of phosphorus pentachloride. The bottle was stoppered tightly and placed in a shaker for 24 hours. The crude acid chloride hydrochloride separated as a tan crystalline material which floated on the top of the carbon tetrachloride and caked the walls of the bottle. The product was scraped from the walls and filtered with a suction funnel accompanied by many washings with carbon tetrachloride to insure complete removal of excess phosphorus pentachloride. The product was not further purified but carried on to the next step.

ir λ_{max}^{Nujol} 5.62 (s), 6.26μ (w), 6.62μ (s) and 6.86μ (s).

nmr (deuterochloroform) τ 6.70, 5.72 and 2.12 (A_2B_2 pattern, $\Delta\nu$ = .43 ppm, J = 8 cps).

Condensation of XXXIX with Triethylamine in Ether. To 8.5 g. (.04 moles) of XXXIX suspended in 500 ml. of refluxing anhydrous ether was added 8.0 g. (0.08 moles) of triethylamine in 250 ml. anhydrous ether. The addition was carried out over a period of about 2 hours under an atmosphere of nitrogen.

Following the addition the reaction mixture was allowed to stir at reflux for about another hour. The ether was then evaporated to leave a brown solid. The solid was dissolved in chloroform and triethylamine hydrochloride was precipitated with hexane. The filtrate was treated with bromine solution to give a small amount of a black solid which was filtered then treated with a small amount of dimethyl sulfoxide. This caused solution of the impurities, leaving behind about 1 mg. of tiny blue crystals, mp 290-305° (dec).

uv $\lambda_{max}^{CHCl_3}$ 623, 416, 392, 368, 314 mμ.

Condensation of "squaric acid" with N,N-dimethylaniline.[13] 11.4 g (.1 moles) of squaric acid and 24.2 g (.2 moles) of N,N-dimethylaniline was added to a solution of 150 ml of 1-butanol and 60 ml. of benzene under reflux. The mixture was refluxed until a total of 3.2 ml. of H_2O was collected by azeotropic distillation - about 4 hours. The reaction mixture was deep blue and on cooling deposited a total of .33 g of a blue powder. The filtrate which was green brown was heated on a steam bath and more benzene was added. The boiling was continued until the solution appeared green. The solution on cooling deposited more blue material. This process was continued until a total of .5 g was collected. The reported yield for the reaction is 9.2 g.[13]

The .5 g material was recrystallized from one gallon of boiling acetic acid to give 249 mg. of "blue product", m.p. >300° (lit. = 276°)[13]

Anal. Calcd. for $C_{20}H_{20}O_2N_2$: C, 73.6; H, 6.58; N, 9.19.

Found: C, 74.3; H, 6.27; N, 8.72.

uv $\lambda_{max}^{CHCl_3}$ 623, 416, 392, 368, 314 mμ; (lit.[13] 628, 414, 389, 366, 306, 263 μ).

ir λ_{max}^{Nujol} 632μ (s) (shoulder at 6.2μ) (no absorption in carbonyl region below 6μ).

nmr τ 6.37 (area = 6), 1.98 (A_2B_2 pattern, $\Delta\nu$ = .83 ppm, J = 10 cps, area = 3.4).

Preparation of the "Purple Product".[19] To a mechanically stirred refluxing solution of 36.9 g (.214 moles) of p-methoxyphenylacetyl chloride in about 300 ml of anhydrous ether, was added 2.16 g (.214 moles) of triethylamine in about 200 ml of the same solvent. The reaction mixture was stirred for two hours following the addition. The reaction mixture was then filtered free of precipitated triethylammonium chloride. The ether solution was evaporated to half its volume and stored in a refrigerator overnight. The precipitated material was combined with another crop of crystals obtained on further concentration of the ether solution. Treatment of a methylene chloride solution of this product with a solution of bromine in the same solvent gave 3.5 g of a purple powder. Recrystallization from a boiling acetonitrile-benzonitrile solution produced 1 gm of beautiful and delicate purple needles mp 212-214° (dec).

Anal. Calcd. for $C_{20}H_{14}O_4$: C, 73.46; H, 4.83.

Found: C, 73.08; H, 4.90.

ir λ_{max}^{KBr} ; 6.1μ (s), 6.3 (s) and no absorption less than 6μ.

uv - visible $\lambda_{max}^{CH_2Cl_2}$ 536 ($\varepsilon = 1.41 \times 10^5$), 500 ($\varepsilon = 4.15 \times 10^4$) and 348 mμ ($\varepsilon = 9.73 \times 10^3$).

nmr (deuterochloroform - trifluoroacetic acid) τ 5.97 (singlet, area = 3) and 2.16 ($\Delta\nu$ = 1.35 ppm, J = 9 cps, area = 4.1).

It is also possible to prepare the "Purple Product" directly from the hydrolysis product of trimer XLVII[15,19].

Reaction of the Purple Product with tropilidene. 300 mg. (1.04 mmoles) of "Purple Product" was added to a solution of 25 ml of 48% fluoroboric acid and 25 ml of acetic anhydride in a teflon bottle. To the mixture was added approximately 180 mg (2 mmoles) of tropilidene. This mixture was allowed to stir at room temperature for 2 hours. During this time a small amount of solid formed. Filtration of the reaction mixture produced a solid which was recrystallized twice from ethyl acetate to give 7.2 mg of material melting at 167°. The solid began to turn pink almost immediately.

ir λ_{max}^{Nujol} 2.9-5.0μ (br,w), 5.75μ (s) and 6.2μ (s).

nmr (Deuterochloroform-trifluroacetic acid) τ 6.20, 6.17 (total area = 6), and 2.99 (A_2B_2 pattern, $\Delta\nu$ = .63 ppm, J = 9 cps).

No white solid formed in this reaction under identical conditions in the absence of tropilidene.

Reaction of the "Purple Product" with 2,4-di-p-methoxyphenyl-3-hydroxycyclobutenone (LIII).[15] 50 mg. of "Purple Product" and 50 mg of dione were added to a solution of 5 ml of 48% HBF_4 and 6 ml of $(CH_3CO)_2O$ in a teflon bottle. The mixture was allowed to stir for 3 hours at room temperature. A solid precipitate formed which after crystallization from ethyl acetate produced enough material for an ir spectrum in nujol.

ir λ_{max}^{Nujol} 2.9-5.0μ (br, w), 5.75μ (s) and 6.2μ (s).

Preparation of 2-bromo-2,4-dimethyl-3-hydroxycyclobutenone (LVII). To 2.16 moles of propionyl chloride and 1120 ml of methylene chloride in a 3-l three necked flask, equipped with a mechanical stirrer and condenser, was added dropwise, over a period of two hours, 2.16 moles of triethylamine in 250 of methylene chloride via a 500 ml addition funnel. The solution was allowed to reflux for an additional two hours followed by stirring at room temperature for a period of ten to twelve hours.

The solid triethylamine hydrochloride was filtered to give an orange solution. The filtrate was then concentrated to about half and again filtered free of precipitated triethylamine hydrochloride. This process was repeated until an orange oil remained. The orange oil, a mixture of both methylketene trimer LV and β-lactone methylketene dimer LVI was not further purified.

The orange oil was diluted to about twice its volume with carbon tetrachloride and to this stirred solution was added a solution of bromine in the same solvent.[19] The addition of bromine was accompanied by the

evolution of a vapor with the odor of propionyl bromide and the precipitation of a white solid. The addition of bromine was continued until it appeared that no further solid formation was occurring. The reaction mixture was then filtered with a suction funnel. Washing the filter cake with benzene gave 21.5 g of a white powder which on recrystallization from an ethyl acetate-benzene mixture produced a first crop of crystals, mp 155-156° (lit.[20] 158-159°), weighing 11.6 g (11.9% based on propionyl chloride). Overall yields in this reaction were variable.

ir λ_{max}^{Nujol} 2.9-4.5μ (br), 5.75μ (s).

nmr (deuteroacetone) (τ) 8.14 (singlet, area = 1) and 8.46 p.p.m. (singlet, area = 1).

Reaction of LVII with trimethylamine. In a typical experiment .88 g of LVII was placed in a clean solvent trap equipped with a magnetic stirring bar and cooled to -78°C. In the trap was condensed about 10 ml of trimethylamine. The Dry Ice-acetone trap was then removed and the reaction mixture was allowed to warm to room temperature with vigorous stirring. The crude reaction product was a cream colored powder from which no products other than alcohol LXI and trimethylammonium bromide could be isolated.

nmr (crude product in deuterodimethyl sulfoxide) (τ) 8.74, 8.56, 8.43, 8.30, 7.19 (doublet, J = 9 cps), and 6.82.

Upon addition af alcohol LVI to the nmr sample of the reaction mixture the absorption at τ 8.74 and 8.56 ppm increased in intensity. Addition of trimethylammonium ion (from $(CH_3)_3NHCl$) increased the intensity of doublet at τ 7.19.

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