The Acetylenic-Oxy-Cope Rearrangement of 1,5-Hexadiyne-3-ol and Methyl Substituted Derivatives

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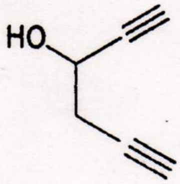
Abstract:

Vapor phase thermolysis of 1,5-hexadiyne-3-ol at 350°C afforded phenol and 4-methylene-2-cyclobuten-1-carboxaldehyde as products. The 4-methyl derivative gave only ortho cresol and 4-ethylidene-2-cyclobutene-1-carboxaldehyde. The 3-methyl and 4,4-dimethyl derivatives yielded no aromatic products. 3-Acetyl-4-methylene cyclobutene was the sole product from thermolysis of the 3-methyl derivative, while 4-isopropylidene-2-cyclobutene-1-carboxaldehyde was the sole product from thermolysis of the 4,4-dimethyl derivative. The phenol and ortho-cresol aromatic products are postulated to result from cyclization of intermediate 1-hydroxy-1,2,4,5-tetraenes (bis allenes), produced by acetylenic oxy-Cope rearrangements. Subsequent supra facial 1,5-hydrogen shifts restore the aromaticity. The 3-methyl and 4,4-dimethyl derivatives cannot aromatize by this pathway. Exclusive formation of ortho cresol eliminates prismane or benzvalene intermediates, as such structures should also produce meta and para cresols. The mechanism of cyclobutene derivative formation for all compounds is proposed to involve cyclization of the identical bis allenes, via diradical pathways. The 3-hydroxy functionality greatly facilitated the rate of the aromatizations, consistent with rate accelerations seen in other oxy-Cope and acetylenic oxy-Cope systems.

Investigation of 1,5-Hexadiyn-3-ols

The effect of two triple bonds upon the oxy-Cope rearrangement was investigated. For this purpose, the following compounds were synthesized and thermolyzed: 1,5-hexadiyn-3-ol (79), 3-methyl-1,5-hexadiyn-3-ol (82), 4,4-dimethyl-1,5-hexadiyn-3-ol (84) and 4-methyl-1,5-hexadiyn-3-ol (86).



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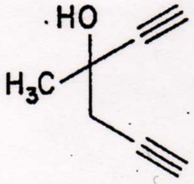

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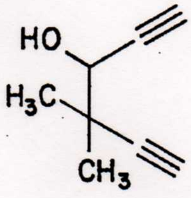

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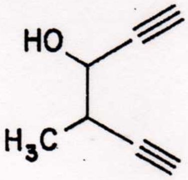

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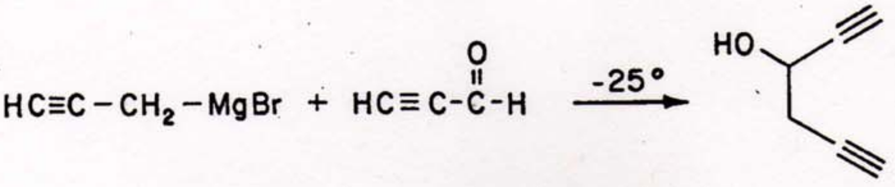
The preparations and thermolysis products obtained will be discussed first.

1,5-Hexadiyn-3-ol (79) was synthesized by the Barbier reaction of propargyl bromide with propargylaldehyde, as described by Sondheimer[33].

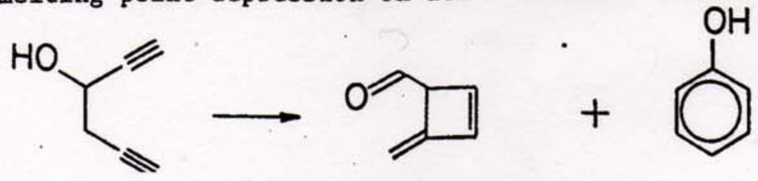


79

The physical constants, infrared and n.m.r. spectra of the compound were consistent with the proposed structure. They are detailed in the experimental section. The compound contained no allenic or internal acetylenic functionalities. Since this compound was fully characterized by Sondheimer[33], no further structure proof was undertaken on it.

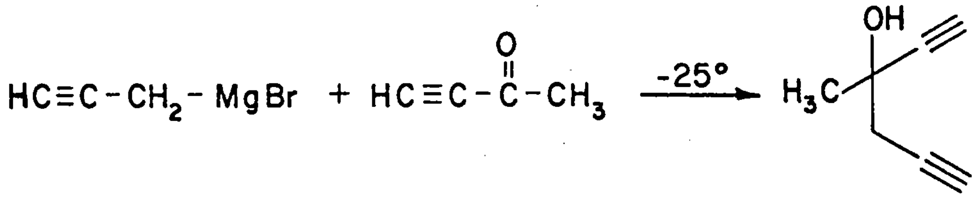
Thermolysis of 79 afforded viscous mixtures containing much polymeric material. V.p.c. analysis indicated two volatile constituents. The lower boiling product proved quite unstable, polymerizing rapidly. It could be isolated in impure form by trap to trap distillation as described in the experimental section. Due to the compound's extreme instability the 4-methylene-2-cyclobutene-1-carboxaldehyde structure (80) was assigned solely on the basis of its n.m.r. spectrum. The spectrum is described in the experimental section. The structure assignment rests on the similarity of the n.m.r. data to that reported for the model compound dimethylenecyclobutene[16].

The higher boiling product was identified as phenol by its odor, v.p.c. retention time, infrared spectrum and tribromo derivative, which showed no melting point depression on admixture with an authentic sample.



No trace of any allenic products or of any propargylaldehyde could be detected in the thermolysis of 1,5-hexadiyn-3-ol.

3-Methyl-1,5-hexadiyn-3-ol (82), previously unreported, was prepared by the low temperature Barbier reaction of propargyl bromide with methyl ethynyl ketone, followed by hydrolysis.



82

The physical constants, elementary analysis, infrared and n.m.r. spectra of 82 were consistent with the proposed structure and are described in the experimental section. Hydrogenation of 82 was quantitative and gave 3-methyl-3-hexanol, identified by comparison of v.p.c. retention time and infrared spectrum with authentic material.

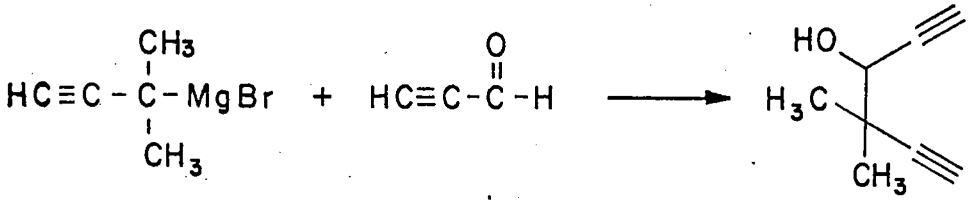
Thermolysis of 82 afforded only one volatile product, in addition to surviving starting material. In addition considerable polymeric material was always present in the crude thermolysis product. The volatile product was extremely prone to further polymerization upon standing or heating, necessitating spectral analysis immediately after isolation. The 3-acetyl-4-methylenecyclobutene (83) structure was assigned to the thermolysis product solely on the basis of its infrared and n.m.r. spectra due to rapid polymerization of the compound. The spectra are described in the experimental section. The infrared spectrum contained bands at 1710 and 875 cm^{-1} ascribable[44] to carbonyl and olefinic methylene absorption respectively. The n.m.r. spectrum is in agreement with the model compound 1,2,3-trimethyl-3-acetyl-4-methylenecyclobutene.[69]

Hydrogenation of the compound gave a saturated ketone which gave a positive iodoform test. The thermolysis product formed a stable 2,4-dinitrophenylhydrazone derivative whose elementary analysis was consistent with the proposed structure.


82 83.

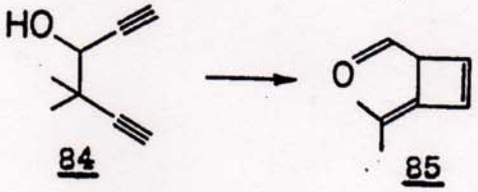
No trace of any allenic, aromatic or cleavage products could be detected in the thermolysis of 82.

4,4-Dimethyl-1,5-hexadiyn-3-ol (84), previously unreported, was prepared by the Barbier reaction of 3-bromo-3-methyl-1-butyne with propargylaldehyde, followed by hydrolysis.


84

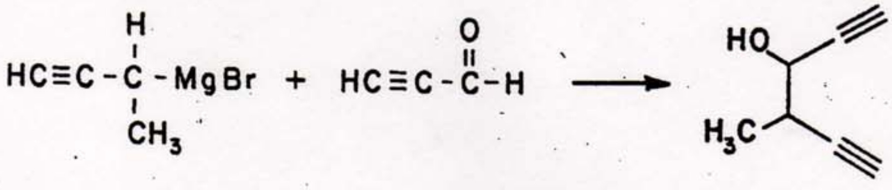
The physical constants, elementary analysis, infrared and n.m.r. spectra of 84 were consistent with the proposed structure and are detailed in the experimental section. The compound appeared homogeneous (v.p.c.) and no traces of allenic or internal acetylenic products were detectable.

Thermolysis of 84 afforded mixtures containing much polymeric material. V.p.c. analysis showed one major thermolysis product constituting 70-80% of the volatile material. Small quantities of two other products were produced but were present in insufficient quantities for isolation and characterization. The major product was isolated free of polymer in about 90% purity as described in the experimental section. The 4-isopropylidene-2-cyclobutene-1-carboxaldehyde (85) structure was assigned to the major product on the basis of its infrared and n.m.r. spectra as detailed in the experimental section. The compound polymerized extremely rapidly on standing, thus precluding further structure proof. The infrared spectrum of 85 showed bands at 1725 and 1630 cm^{-1}, indicative[44] of carbonyl and olefinic functionalities respectively. The n.m.r. spectrum was quite similar to that reported for the model compound di-isopropylidenecyclobutene.[18]



The product formed a stable 2,4-dinitrophenylhydrazone whose elementary analysis and n.m.r. spectrum were consistent with the structure. Infrared spectra of crude thermolyses mixtures from the thermolysis of 84 indicate no trace of any allenic or aromatic products.

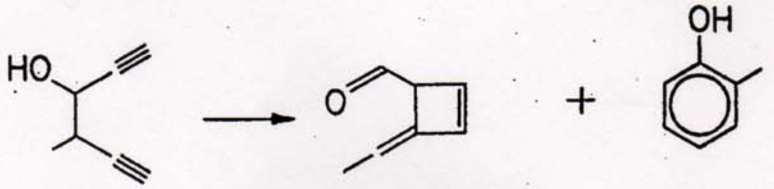
4-Methyl-1,5-hexadiyn-3-ol (86), previously unreported, was prepared by the Barbier reaction of 3-bromo-1-butyne with propargylaldehyde, followed by hydrolysis.



The physical constants, elementary analysis, infrared and n.m.r. spectra of 86 were consistent with the proposed structure. They are detailed in the experimental section. The material appeared homogeneous (v.p.c.) and no trace of allenic or internal acetylenic products could be detected. Hydrogenation of 86 gave a mixture of 4-methyl-3-hexanone and 4-methyl-3-hexanol, identified by comparison of v.p.c. retention times with authentic materials[4].

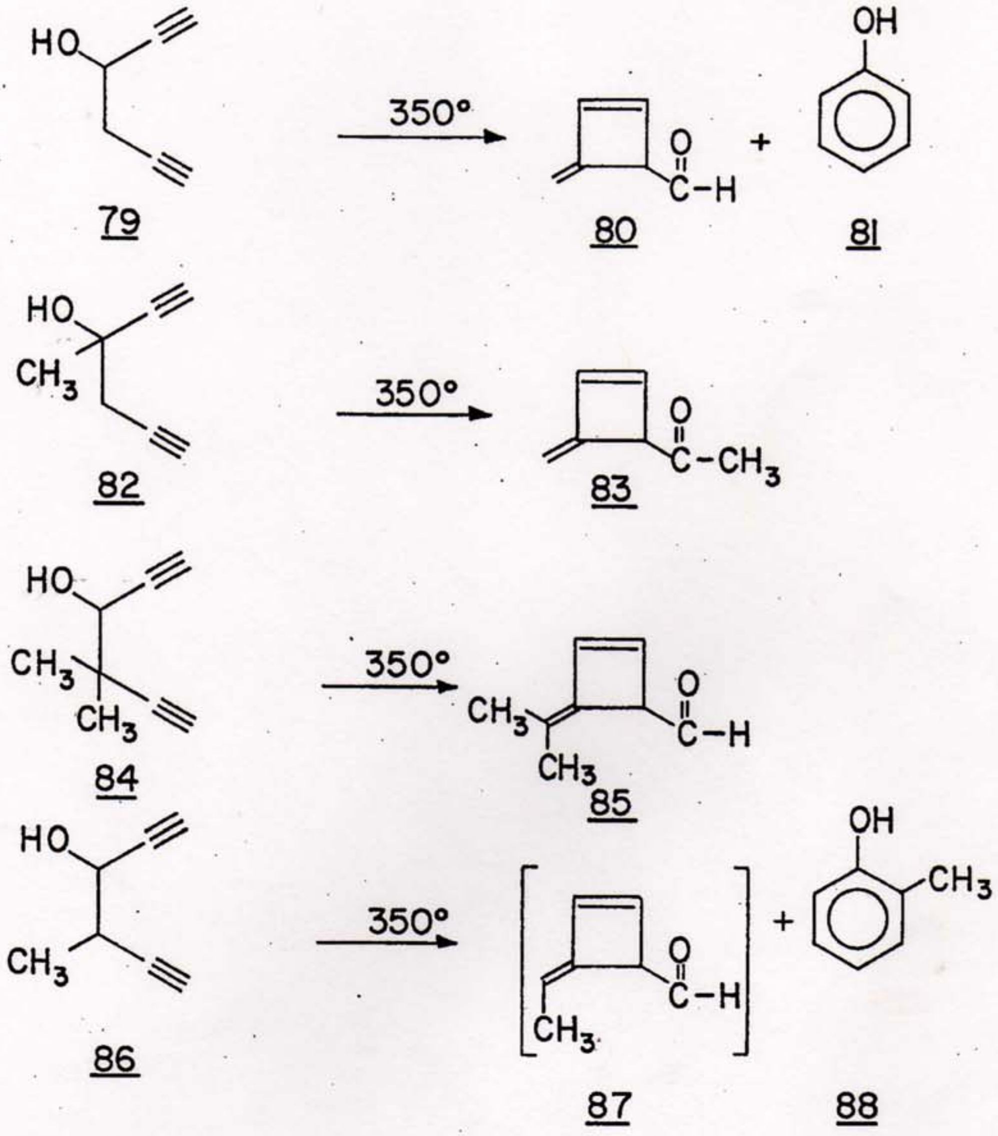
As with the thermolysis of the previously described diacetylenic alcohols, thermolysis of 86 yielded a viscous product containing much polymeric material. V.p.c. showed the volatile constituent to consist of two components in a 7:3 ratio. The minor product is believed to be the corresponding 4-ethylidene-2-cyclobutene-1-carboxaldehyde (87) on the basis of its v.p.c. retention time and by analogy with the other systems studied. Due to the small amount of material available and its tendency to polymerize, this component could not be isolated.

The major component, isolated by distillation under aspirator pressure, was shown to be o-cresol by its v.p.c. retention time and infrared spectrum, both of which were identical to those of authentic o-cresol but quite different from those of the m- and p-isomers. The major component formed a bromo derivative which showed no melting point depression on admixture with an authentic sample.



86 87 88

PLATE


HO
350°
O
C–H
+
OH
79
80
81
HO
CH$_3$
350°
O
C–CH$_3$
82
83
HO
CH$_3$
CH$_3$
350°
CH$_3$
CH$_3$
O
C–H
84
85
HO
CH$_3$
350°
O
C–H
CH$_3$
+
OH
CH$_3$
86
87
88

The reactions discussed in the thermolyses of the above diacetylenic alcohols are summarized on plate

Table indicates the dependency of phenol production, from <u>79</u>, on temperature and residence time.

<u>Table</u>

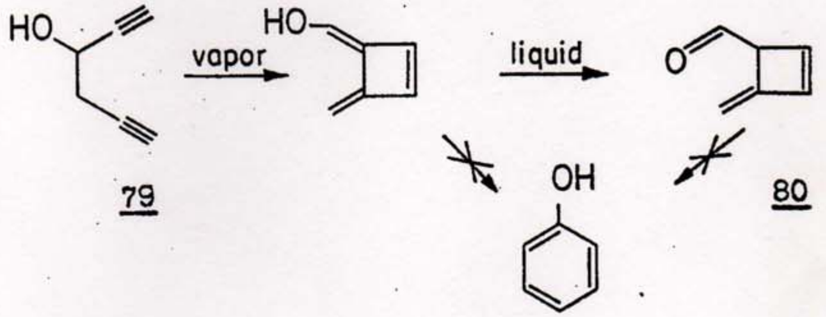
Temperature and Residence Time Effects on Phenol Formation

t°C	Pmm	% Phenol
350	0.5	detonation
"	3	8
"	25	43
370	3	6
"	5 H_2O trap	10
"	20	48

At shorter residence time (lower pressure) the amount of polymeric material increased as phenol formation fell off. The amount of phenol produced was measured using an internal standard as described in the experimental section. The percentage of cyclobutene product, <u>80</u>, could not be measured quantitatively due to its extreme instability.

A thermolysis of <u>79</u>, performed at 350° and 0.5 mm, afforded a product mixture which decomposed explosively upon warming to near room temperature. Consequently, the possibility of a phenol precursor such as cyclohexadienone which could either produce phenol or polymerize in the liquid phase, after condensation, was considered. To test this hypothesis, a thermolysis was performed at 370° and 5 mm and the vapors were condensed in traps containing cold water. Although these conditions should greatly facilitate any intermolecular, liquid phase, hydrogen shifts required for phenol formation, only the expected amount of phenol, about 10%, was obtained.

By analogy with the results reported from the thermolysis of 1,5-hexadiynes[16], the primary products expected from the diacetylenic alcohols 79, 82, 84 and 86 are the enolic precursors of the observed carbonyl products 80, 83, 85 and 87. The fact that thermally produced enols survive in the gas phase with ketonization occurring only in the liquid state has previously been explained. The carbonyl components of the above product mixtures were shown not to be precursors to the aromatic products, since a sample of 80 in dilute deuterochloroform solution showed no n.m.r. spectral changes after standing for five days.



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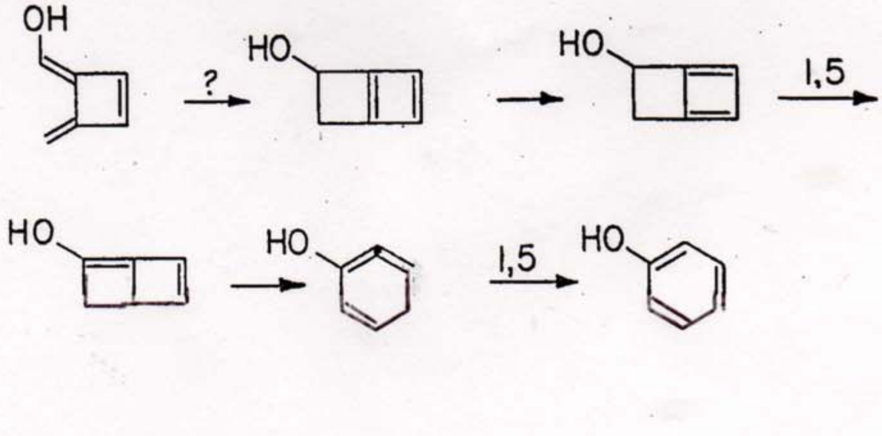
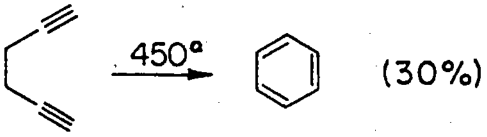
80

81

Another possible mechanism considered for formation of the aromatic products involves the enolic precursor of 80 by a reaction sequence such as the following.



However, such mechanisms are discounted by the following argument. It appears that formation of the aromatic ring is greatly facilitated by the presence of the hydroxy function. For example, thermolysis of 1,5-hexadiyne at 450° produced 30% benzene[19] while thermolysis of 79 produced 43% phenol at only 350°.



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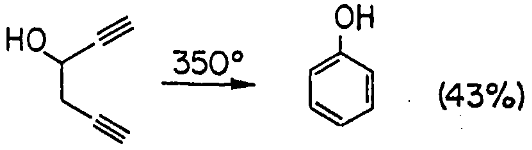


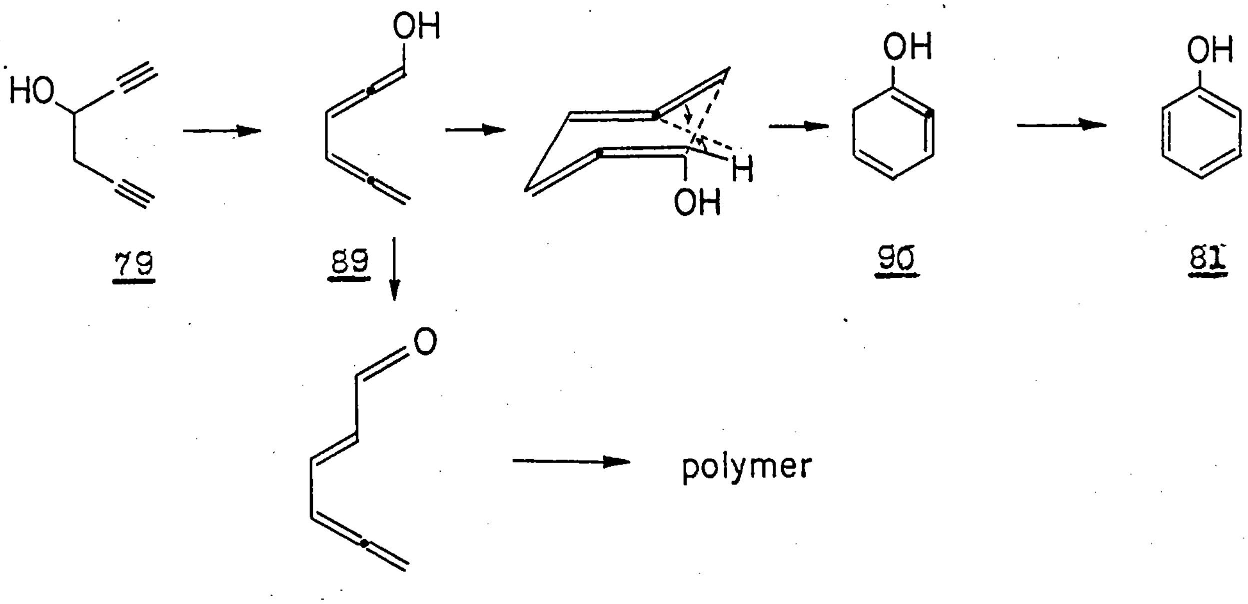
79 81

Although it is difficult to compare reaction conditions as reported by different investigators, it would appear that residence times in this work were considerably less than in the work of Coller[19]. It may be concluded then, that under conditions of identical length of exposure, the differences between amounts of benzene and phenol formation would be even greater.

Now the first step in the above mechanism is a butadiene-cyclobutene isomerization to form a cyclobutadiene in the fused ring. This step should require an activation energy which is increased by the presence of the hydroxyl function since it involves a disruption of the oxygen lone pair interaction with the ethylenic π system. Berson[50] has shown that a perturbation due to an oxygen on an ethylenic function stabilizes the system relative to the unsubstituted molecule. Therefore the enolic precursor should possess a lower ground state energy than the corresponding unsubstituted dimethylenecyclobutene. Since aromatization is facilitated by the

The fact that increased residence time in the thermolysis zone leads to increased phenol formation is indicative of an intermediate whose rate of formation is fast compared to its rate of decay along the pathway leading to phenol. The formation of o-cresol, as the only phenolic product from 86, eliminates any prismane or benzvalene intermediates since such structures should result in some m- or p-cresol formation. The complete absence of phenolic products in the thermolyses of 82 and 84 indicates that phenol formation requires hydrogen migration from both carbons 3 and 4 and also renders unlikely any potential hydroxyl migration or carbon skeletal rearrangements.

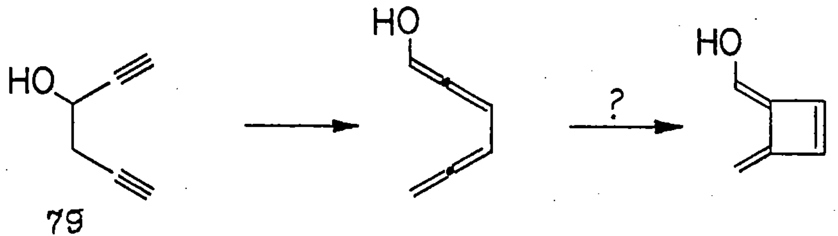
A mechanism which seems to fit all the above considerations is phenol formation via the oxy-Cope pathway.



79 89 90 81

The cyclic allenol intermediate 90, which represents a more stabilized cyclic allene than the similar intermediate suggested by Bergmann[20], can arise from the oxy-Cope product 89 by means of a 1,2-cycloaddition of the terminal hydrogen as indicated. The cyclic allenol can undergo a 1,5 hydrogen shift and thus produce phenol in the vapor state. This step is in accord with the fact that there was no increase of phenol formation by condensation into a prototropic medium. As pointed out earlier, the intermediate 89 should form rapidly, via the low energy oxy-Cope pathway, compared with its decay rate to phenol, via the higher energy cycloaddition. Polymer would result from ketonization of 89, after condensation, since the resulting hexatrienal cannot be expected to survive in an acidic medium.

Whether cyclobutene formation occurs directly from the starting alcohol or proceeds through the Cope product remains conjectural. An internal allene dimerization[53] of 89, a pathway considered by Huntsman, can account for cyclobutene formation.



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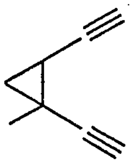
Disubstitution as in compounds 27 or 50 would prevent formation of benzene derivatives from the primary Cope product.



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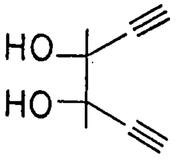

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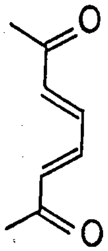

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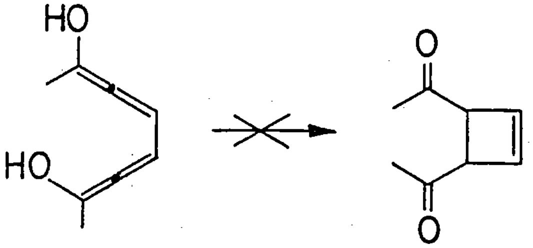
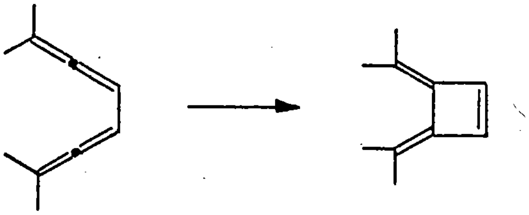
However, the report of Chuche[28] is not in agreement with this scheme. Since the results of Skattebol[18] show that tetra substitution at the termini of the 1,2,4,5-hexatetraene system does not block cyclobutene formation, Chuche's terminal Cope product seems to require an alternate path for cyclobutene formation.



Chuche & Manisse

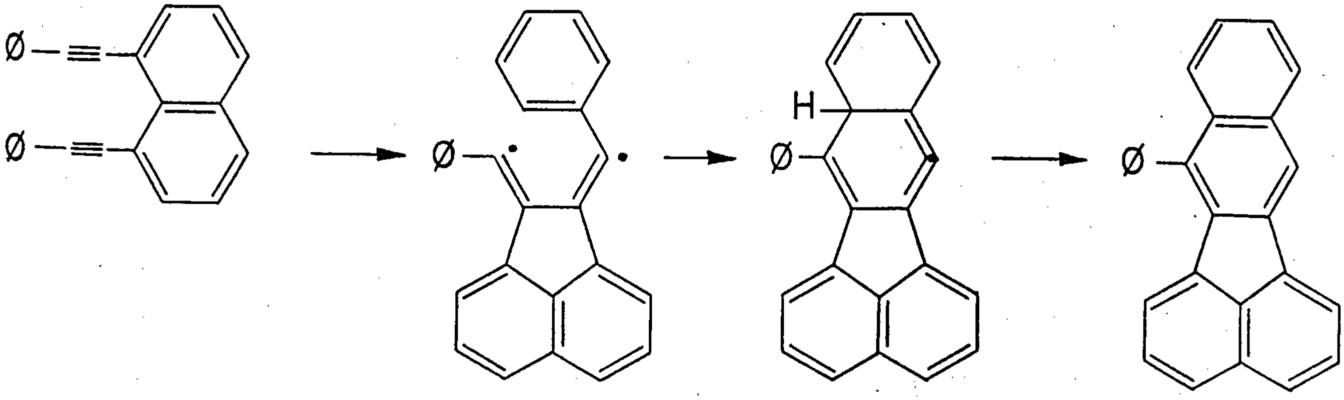


26a

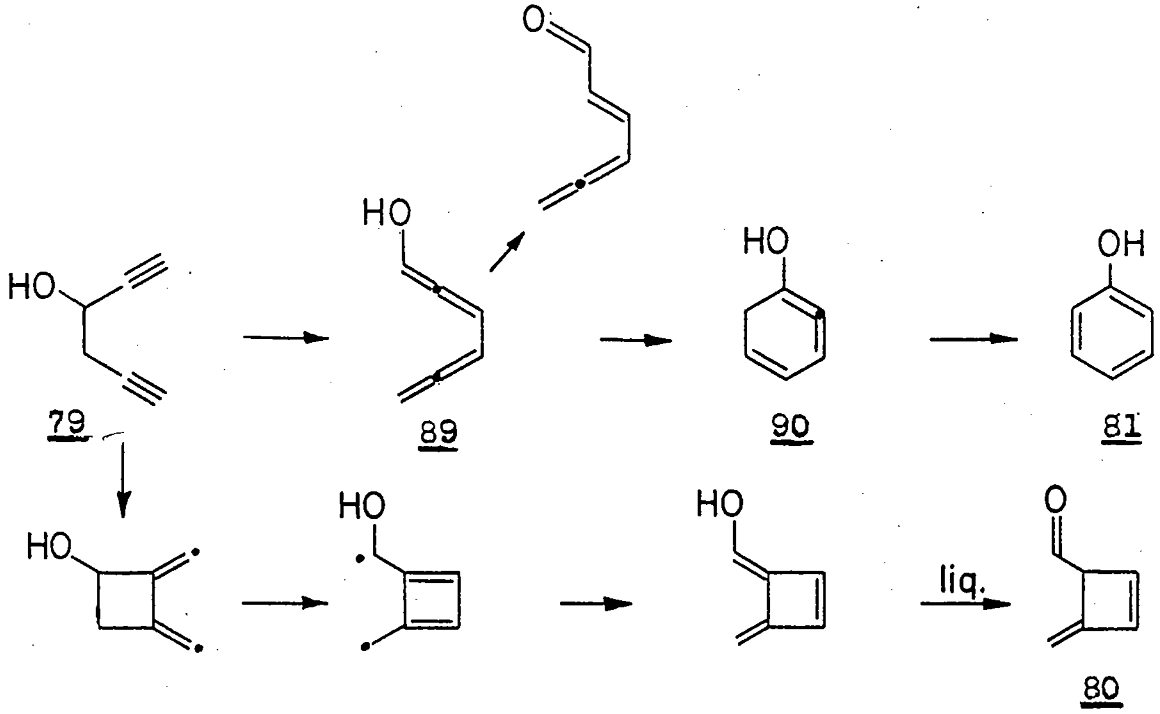
Skattebol & Solomon,

Olefin stabilization by the two hydroxyl functions in the enolic precursor to 51 cannot account for lack of cyclization since only the inner double bonds of the allenic systems would be involved.

Schechter[54] has proposed the following scheme in a similar system.



The possible formation of the cyclobutenes by a diradical pathway analogous to that above is here proposed.



A concerted ring closure-ring opening of the initially produced diradical results in a diallylic resonance stabilized diradical which collapses to the final product. This pathway avoids the necessity of invoking the various highly strained, fused ring cyclobutadienyl systems[19,20] that plague alternate mechanistic suggestions. The diradical pathway is actually a multistep version of the concerted 10 electron one-step mechanism originally proposed by Huntsman[16] but rejected by Coller et al.[19] on molecular orbital grounds. Stereospecificity is maintained by the diradical pathway since, following the concerted ring opening-ring closure step, geometry is maintained by the necessity of π orbital overlap in the forming allylic radical and the rotational restraint inherent in the cyclic system. Tetrasubstitution as in 50 would result in substantial steric crowding in the initial diradical produced and could render this pathway incapable of competition with the Cope process.

The fact that Chuche[28] did not observe cyclobutene formation from the bis-allenol intermediate, as might be expected from the results of Skattebol[18], could be the result of intramolecular H-bonding which must be disrupted in any cyclization process.

It is worthy of note that only in the thermolysis of 50 is the concurrent formation of β-hydroxyacetylene cleavage products reported. It was demonstrated earlier in this thesis that the latter reaction can compete with the acetylenic Cope process. The absence of this reaction in the thermolyses of the diacetylenic alcohols here reported is indicative of a more facile reaction with which the cleavage cannot compete and only in the absence of cyclobutene formation is it observable. This fact is also in accord with the proposed low energy pathway for cyclobutene formation.

EXPERIMENTAL SECTION

Melting points and boiling points are uncorrected. Infrared spectra were determined with Beckmann IR-5A or IR-8 spectrophotometers on neat liquid samples. N.M.R. spectra were determined with a Varian A-60A spectrometer on neat liquid samples or in deuterated chloroform solutions with an internal tetramethylsilane standard. N.M.R. spectral interpretations were based upon "Spectrometric Identification of Organic Compounds" by Silverstein and Bassler. Ultraviolet spectra were determined with a Bausch and Lomb Spectronic 505 on spectro grade "Isootane" solutions. Vapor phase chromatographic analyses were obtained with a F and M Model 500 using 2-or 5-ft. columns packed with 10% SE-30 on acid washed Chromosorb- P or 20% Triton X-305. Relative peak areas were determined with a disc integrator. Preparative vapor phase chromatography was accomplished with a F and M Model 776 using 8 ft. X 1 inch columns packed with silicone grease or Triton-X as described above. Elementary analyses were performed by Dr. Stephen M. Nagy, Belmont, Mass.

Fractional distillations were accomplished by means of a "tantalum wire column" or a spinning band column. The "tantalum wire column" was a 45 cm X 7 mm column packed with a spiral of tantalum wire. The column was enclosed in a glass jacket wound with Nichrome wire by which external heat was applied as needed. The spinning band column was a Nester Faust Model No. NF-120, 8 mm X 61 cm., equipped with a dual temperature controller and

#306 duo set timer for automatic control of the reflux ratio.

The technique of "flash distillation" was often employed to remove non volatile materials from crude reaction mixtures. The procedure consisted of slowly dropping the material into a 3-neck flask heated to a temperature well above the expected distilling temperature while maintaining the system under appropriate reduced pressure. The volatile constituent was trapped with a water condenser and collected. Non volatile materials accumulate in the still pot.

Thermal Vapor Phase Rearrangements

The apparatus used, see diagram I , consisted of a vertical Pyrex column, 22 mm o.d., packed with 1/16 inch i.d. Pyrex helices for a length of about 45 cm. The packed portion of the column was divided into three equal sections, each individually wrapped with resistance wire connected to a variac, and in the center of each section was a well containing a 500° thermometer. A dropping funnel attached to the top of the column admitted the sample, usually at a rate of four to ten drops per minute, and a capillary inlet just below the funnel maintained an atmosphere of dry nitrogen. The vapors were condensed at the bottom of the tube by means of one or two flasks in series cooled with a Dry Ice-acetone bath. The system was evacuated, by means of a water aspirator or vacuum pump, through a drying tube in the vacuum line to protect the system from water vapor. Pressures were regulated by means of a bleed valve attached to the stopcock opening on the safety trap attached to the aspirator. The condensed products, usually representing a recovery of 70-90%, were subjected to analyses by vapor phase chromatography. Low boiling hydrocarbon components condensed only partially under these conditions and appeared as minor peaks in the vapor phase chromatograms. The condensed products were separated by fractional distillation or preparative vapor phase chromatography. Each of the compounds reported was thermolyzed numerous times and a typical experiment is given for each compound along with the structure proofs for the thermolysis products.

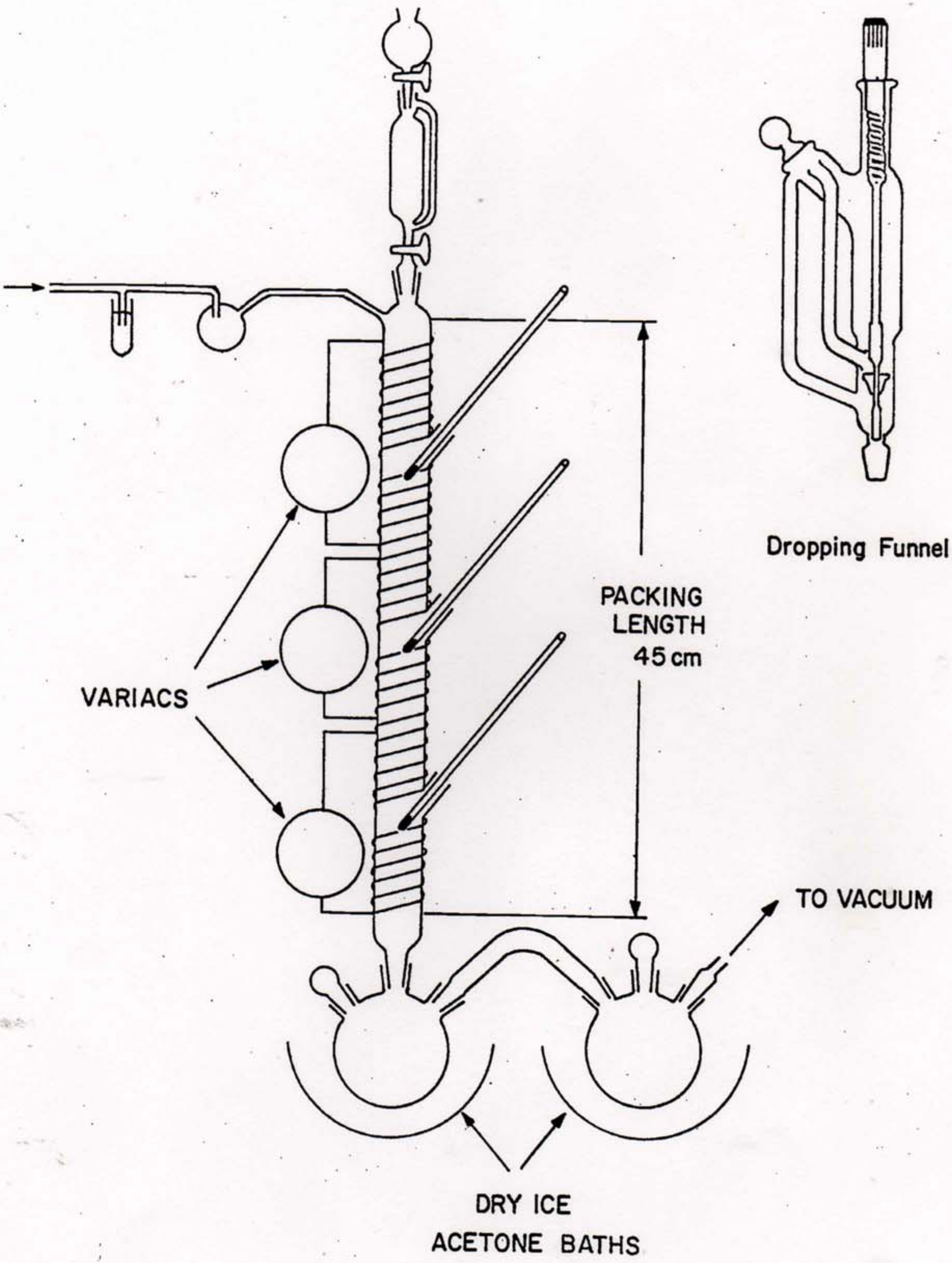


Diagram I

Thermolysis Apparatus

Preparation of 1,5-hexadiyn-3-ol (79)

This compound was prepared by the Sondheimer procedure.[33] In a 1 liter three neck flask, equipped with mechanical stirrer, dropping funnel and condenser, were placed 24 g (1 mol) Mg turnings, 150 ml dry ether, 3 g redistilled propargyl bromide, and 0.1 g $HgCl_2$. The mixture was warmed, with stirring, until a reaction commenced as evidenced by vigorous boiling of the ether. The flask was then immersed in a Dry-Ice-acetone bath at -35° and a solution of 57 g redistilled propargyl bromide (total 0.5 mol) and a 14 g propargyl aldehyde (0.26 mol) in 150 ml ether was added over a period of 3.5 hours, while the bath temperature was maintained at -30° to -40°. The mixture was allowed to warm to room temperature, decomposed over ammonium chloride-ice, and the ether layer was separated. The aqueous layer was extracted twice with 50 ml of ether and the combined ether extracts were then washed several times with 10 ml portions of water. After drying with magnesium sulfate, the ether was evaporated to yield a dark brown oil. Flash distillation followed by careful fractionation under aspirator pressure yielded 11.7 g (48%) of v.p.c. pure material. B.p. 79-80°/25 mm, n_D^{25} 1.4728 (lit.[33] b.p. 73-75°/20 mm, n_D^{25} 1.4728).

The infrared spectrum showed bands at 3400(s), 3300(spike), 2900(w), 2130(w), 1420(m), 1395(m), 1300 (m), 1220(w), 1190(w), 1050(s), 980(w), 955(m), 935(w), 880(w), 850(m), 810(w), 790(w), 705(m), and 650(s) cm^{-1}.

The n.m.r. spectrum (δ scale) showed a triplet at 2.2 (1H, acetylenic), a broad singlet at 3.4 (1H, hydroxyl), overlapping doublets at 2.75 and 2.63 (total 3H, aliphatic and one acetylenic), and a triplet split into doublets at 4.6 (1H, methine proton).

Vapor phase thermolyses of 1,5-hexadiyn-3-ol (79)

This compound was thermolyzed at temperatures ranging from 300° to 370° and at various pressures. Complications and hazards were encountered during the thermolyses of this compound not found in other thermolyses. Appreciable polymerization and carbonization were observed in the thermolysis column at all temperatures employed. Another complication was the tendency of the thermolyzed material to solidify in the cooler regions of the column before reaching the cold trap. Also, the thermolyzed material was extremely unstable upon warming, even to room temperature. In one experiment, as the thermolysis mixture was being weighed on a Mettler balance, the mixture suddenly warmed, and then exploded, disintegrating the container and shattering the glass sides of the balance. The thermolyses mixtures obtained were thick syrups containing polymeric material. V.p.c. of the crude thermolyses mixtures indicated a major volatile thermolysis product which proved to be phenol. A lower boiling constituent was also detected which proved to be 4-methylene-2-cyclobutene-1-carboxaldehyde. This compound could not be isolated by micro distillation since it polymerized when heated in the presence of phenol. Its isolation is described later.

In a typical experiment, 3.08 g of 1,5-hexadiyn-3-ol was passed through the thermolysis column at 370°and 15 mm pressure. A drop rate of four drops/minute was employed. 2.37 g of thick oily product was recovered (77%). V.p.c. of the crude product showed two volatile constituents the major of which was phenol. The product was micro distilled under 0.1 mm pressure until rapid polymerization began in the distilling pot, whereupon distillation was discontinued. Approximately 1 g of volatile product was obtained which partially solidified on standing. V.p.c. of the material showed it to be about 80% phenol. Therefore the phenol was obtained in a yield of 0.8 g (26%).

The volatile thermolysis product had an infrared spectrum superimposable on that of authentic phenol. The product gave a positive test for phenol with bromine water. On treatment with excess bromine water, the thermolysis product gave a white solid, which, when recrystallized from 50/50 water-ethanol, melted at 95-96° (lit.:[60] m.p. 95°). The derivative gave no melting point depression on admixture with an authentic sample of 2,4,6-tribromophenol.

4-Methylene-Δ^2-cyclobutenecarboxaldehyde (80)

The low boiling minor component obtained in addition to phenol was identified via n.m.r. spectroscopy, by comparison with literature reports of similar compounds.[69] The material was obtained free of polymer but contaminated with phenol. The thermolyzed product was collected in the first of two traps set in series. The trap was let come to room temperature and the second trap cooled to -78°. Trap to trap distillation was then accomplished by heating the first trap gently with a warm water bath while the pressure was reduced to 1 mm. After one half hour the contents of the second trap were analyzed by v.p.c. and n.m.r. V.p.c. indicated an approximately 1:1 mixture of the low boiling product and phenol. The n.m.r. (δ scale) showed in addition to the phenol multiplet at 7.0, the following peaks: a doublet (J=5 cps) with long range splitting at 3.95 (1H, methine), multiplets at 4.70 and 4.95 (2H, olefinic), a singlet at 6.65 (2H, ring olefinics), and a doublet (J=5 cps) at 9.41 (1H. aldehydic).

Thermolyses of 1,5-hexadiyn-3-ol employing an internal standard.

Several small samples of 1,5-hexadiyn-3-ol, diluted with benzene and n-hexyl alcohol, were thermolyzed at 350° and 370° and at high and low pressures. The benzene served as an inert diluent and the hexyl alcohol as an internal standard. The integral ratio of acetylenic alcohol to hexyl alcohol was determined initially by v.p.c. After thermolysis, the product was analyzed by v.p.c. and the integral ratio of hexyl alcohol to phenol was computed. By this procedure the absolute percentage of phenol produced was calculated as a function of temperature and pressure. The results are summarized in table.

The following methyl substituted 1,5-hexadiyn-3-ols were synthesized, using procedures analogous to that employed in the above synthesis of 1,5-hexadiyn-3-ol.

3-Methyl-1,5-hexadiyn-3-ol. (82)

24 g (1 mol) magnesium, 0.1 g mercuric chloride and 56 g (0.5 mol) propargyl bromide were treated with 23 g (0.34 mol) of methyl ethynyl ketone (Farchan Laboratories). The yield was 36.8 g(66%) b.p. 50°(10 mm), n_D^{25} 1.4628, d_4^{23} 0.9288.

Anal. Calcd. for C_7H_8O: C, 77.95; H, 7.46.
Found : C, 77.59; H, 7.30.

The infrared spectrum showed bands at 3400(s), 3300(spike), 2980(m), 2900(w), 2120(w), 1450(m), 1420(m), 1380(s), 1360(s), 1290(m), 1260(m), 1160(m), 1130(s), 1090(s), 950(m), 940(m), 910(w), 875(m), and 650(s) cm^{-1}.

The n.m.r. spectrum (δ scale) showed a singlet at 1.65 (3H, methyl), a triplet at 2.25 (1H, acetylenic), a singlet at 2.65 (1H, acetylenic), a doublet centered at 2.65 (2H, methylene), and a broad singlet at 3.30 (1H, hydroxyl).

Hydrogenation of 3-methyl-1,5-hexadiyn-3-ol (82)

A 1.14 g sample of the alcohol, in methanol, over Pd/C, was found to absorb 1030 ml of hydrogen at 298°K, which was 101% of the 1020 ml theoretically required to saturate four double bonds. The methanol was evaporated, yielding a colorless liquid, which was analyzed by v.p.c. A single peak was observed whose retention time was equal to that of authentic 3-methyl-3-hexanol. The infrared spectrum of the hydrogenated material was also identical to that of authentic 3-methyl-3-hexanol.

Vapor phase thermolyses of 3-methyl-1,5-hexadiyn-3-ol (82)

This compound was thermolyzed at temperatures ranging from 320° to 380° and at various pressures. At all temperatures substantial polymerization occurred in the cooler regions of the thermolysis column, resulting in a viscous, dark brown thermolysis product. Since the product slowly solidified on standing to a polymeric material, it was necessary to analyze the material immediately after recovery. V.p.c. of the crude thermolyses mixtures showed them to contain a single volatile product in addition to surviving starting alcohol. Increase in temperature or pressure of the system resulted in less recovered starting material and increased polymerization. At higher temperatures, a small amount of another volatile constituent was detected, but was present in insufficient quantity for characterization. The 3-acetyl-4-methylenecyclobutene structure was assigned to the thermolysis product. Infrared spectra of the crude thermolyses mixtures showed no trace of aromatic or allenic products.

In a typical experiment, 1.59 g of the alcohol was thermolyzed at a pressure of 5 mm and a temperature of 330°. The condensed product was dark yellow and weighed 1.23 g (77% recovery). V.p.c. of the product showed it to contain 80% 3-acetyl-4-methylene-cyclobutene and 20% unreacted starting alcohol, **in its volatile constituency.**

3-Acetyl-4-methylenecyclobutene (83)

The thermolysis product could be isolated by rapid distillation under aspirator pressure. Usually only a small forerun of the material could be collected before the remaining material in the pot rapidly polymerized to a dark mass. The colorless distillate rapidly turned brown and polymerized. However, infrared and n.m.r. spectra could be obtained on the compound immediately after its isolation.

The infrared spectrum showed bands at 3080(w), 2980(w), 2930(w), 1710(s), 1670(s), 1600(w), 1420(m), 1360(s), 1320(m), 1280(m), 1230(s), 1165(m), 1130(m), 1000(w), 950(w), 875(m), 820(m) and 770(m) cm^{-1}.

The n.m.r. spectrum (δ scale) showed 2 doublets with fine splitting at 6.55 and 6.75 (2H, J=3 cps, ring olefinics), multiplets at 4.65 and 4.85 (2H, terminal methylene), a broad singlet at 4.05 (1H, methine), and a singlet at 2.15 (3H, methyl).

The compound formed a 2,4-dinitrophenylhydrazone by the procedure of Shriner and Fuson.[60] Three recrystallizations from 50/50 ethanol/ethyl acetate yielded yellow crystals, m.p. 117-118°.

<u>Anal.</u> Calcd. for $C_{13}H_{12}N_4O_4$: C, 54.17; H, 4.25.
Found: C, 54.14; H, 4.76.

The n.m.r. spectrum of the derivative (δ scale) showed a broad singlet at 11.05 (1H, N-H), doublets at 9.08, 8.20 and 7.90 (3H, aromatics), two doublets at 6.55 and 6.75 (2H, ring olefinics, J=3 cps), a broad singlet at 4.20 (1H, methine), broad singlets at 4.83 and 4.60 (2H, terminal methylene), and a singlet at 2.0 (3H, methyl).

Hydrogenation of crude 3-Acetyl-4-methylenecyclobutene.

A crude thermolysis mixture was placed in pentane, over Pd/C, immediately after thermolysis. The crude mixture was hydrogenated until gas absorption ceased. After filtering the catalyst and evaporating the pentane, the crude product was micro distilled and was then analyzed by v.p.c. A single hydrogenation product was observed, whose infrared spectrum indicated it to be a saturated ketone. The ketone gave a positive iodoform test. Attempts to convert the saturated acid from the haloform reaction to its amide derivative were unsuccessful.

4,4—Dimethyl-1,5-hexadiyn-3-ol (84)

24 g (1 mol) magnesium, 0.1 g mercuric chloride and 42 g (0.31 mol) 3-bromo-3-methyl-1-butyne were reacted with 15 g (0.28 mol) of propargyl aldehyde. The bromide was synthesized by the reaction of phosphorous tribromide with 2-methyl-3-butyn-2-ol (Airco Chemical Co.). The yield of 4,4-dimethyl-1,5-hexadiyn-3--ol was 7.55 g (22%). B.p. 57-8°(10 mm), n_D^{28} 1.4613.

Anal.	Calcd. for $C_8H_{10}O$:	C, 78.65;	H, 8.25.
	Found :	C, 78.80;	H, 8.24.

The infrared spectrum showed bands at 3400(m), 3300(spike), 2980(m),2940(w),2900(w),2120(w),1470(m),1390(m),1370(m),1310(w), 1260(m),1210(w),1140(w),1060(s),1020(m),970(w),940(w),860(w), and 650(s) cm^{-1}.

The n.m.r. spectrum (δ scale) showed a singlet at 1.35 (6H, methyl), a singlet at 2.25 (1H, acetylenic), a doublet (J=2 cps) at 2.55 (1H, acetylenic), a doublet at 2.85 (J=7 cps,1H, hydroxyl, collapses with D_2O), and a doublet of doublets at 4.23 (J_1=7 cps, J_2=2 cps, 1H, methine), which collapsed to a doublet (J=2 cps) on shaking the sample with D_2O.

Vapor phase thermolyses of 4,4-dimethyl-1,5-hexadiyn-3-ol(84)

This compound was thermolyzed at 350°and at various pressures. Substantial polymerization occurred in the cooler regions of the thermolysis column and in the recovery pot. The thermolyzed products were dark brown and quite thick. Since the thermolyzed material rapidly hardened to a brown solid upon standing, it was necessary to work up and analyze the material immediately. V.p.c. of the crude product showed it to contain three constituents, the major of which was always present in a 70-80% concentration. No significant amount of aromatic or allenic products could be detected in the crude product by infrared spectroscopy. Starting material was not detected in any of the recovered products from the various thermolyses. The major thermolysis product could be isolated by rapid micro distillation of the product at aspirator pressure. Although hydroquinone was always added to the still pot to inhibit polymerization, usually only about 25% of the material would distill before the remainder would harden to a dark polymeric mass. This procedure afforded the major thermolysis product, free of polymer, in about 90-95% purity. The material was contaminated by a high boiling minor thermolysis product. Neither the low nor high boiling minor thermolysis products could be isolated and identified. The 4-isopropylidene-Δ^2-cyclobutenecarboxaldehyde structure was assigned to the major product solely on the basis of its infrared and n.m.r. spectra, due to rapid polymerization of the compound.

In a typical experiment, 1.91 g of 4,4-dimethyl-1,5-hexadiyn-3-ol was thermolyzed at 350-5° and a pressure of

22 mm. The recovered material weighed 1.19 g (63% recovery). V.p.c. analysis showed that 75% of the volatile material consisted of 4-isopropylidene-Δ^2-cyclobutenecarboxaldehyde, 15% of a very low boiling cleavage product and 10% of a higher boiling product.

4-Isopropylidene-Δ^2-cyclobutenecarboxaldehyde (85)

This material was isolated in about 90% purity by the procedure described above. Since it polymerized to a brown solid rapidly upon standing, spectral analyses were undertaken immediately after isolation.

The infrared spectrum showed bands at 3030(w), 2950(m), 2900(m), 2850(m), 2800(m), 2700(m), 1725(s), 1700(s)1670(m), 1630(m), 1450(m), 1380(m), 1300(m), 1270(m), 1240(w), 1205(m), 1170(m), 1090(m), 1060(m), 785(m), 750(s), and 715(m) cm^{-1}.

The n.m.r. spectrum (δ scale) showed a singlet at 1.60 (3H, methyl), a singlet with long range quartet splitting at 1.80 (3H, methyl), a doublet (J=6 cps) at 3.85 (1H, methine proton), a doublet (J=2.5 cps) with long range splitting at 6.40 (1H, ring olefinic), a doublet (J=2.5 cps) at 6.83 (1H, ring olefinic), and a doublet (J=6 cps) at 9.25 (1H, aldehydic).

A 2,4-dinitrophenylhydrazone was prepared by the method of Shriner and Fuson.[60] Repeated recrystallization from 50/50 ethanol/ethyl acetate yielded yellow crystals, m.p. 146-7°.

Anal. Calcd. for $C_{14}H_{14}N_4O_4$, C, 55.63; H, 4.67.

Found: C, 55.70; H, 5.05.

The n.m.r. spectrum (δ scale) of the dinitrophenylhydrazone showed singlets at 1.70 and 1.85 (6H, methyl), a doublet (J=8 cps) at 4.20 (1H, methine), a doublet with additional fine splitting at 6.45 (1H, ring olefinic, J=3 cps), a doublet at 6.70 (J=3 cps, 1H, ring olefinic), a doublet (J=8 cps) at 7.40 (1H, -CH=N), doublets at 7.95, 8.40 and 9.17 (3H, aromatics), and a broad singlet at 11.17 (1H, N-H).

4—Methyl-1,5-hexadiyn-3-ol (86)

12 g (0.5 mol) magnesium, 0.1 g mercuric chloride and 27 g (0.2 mol) 3-bromo-1-butyne were reacted with 10 g (0.18 mol) of propargyl aldehyde. The bromide was synthesized by the reaction of phosphorous tribromide with 3-butyn-2-ol (Farchan Chemical Co.). The yield of 4-methyl-1,5-hexadiyn-3-ol was 4.70 g (24%), B.p. 86-7°(40 mm), n_D^{24} 1.4653.

Anal. Calcd. for C_7H_8O : C, 77.95; H, 7.46.

Found: C, 78.26; H, 7.70.

The infrared spectrum showed bands at 3400(s),3300 (spike), 2980(m),2940(m),2900(m),2880(m),2120(w)1460(m),1380(m),1290(m), 1120(m),1080(m),1065(m),1030(s)975(m),880(w),835(w),795(w),755(w), and 650(v.s.) cm^{-1}.

The n.m.r. spectrum (δ scale) showed two doublets (J=7 cps) approximately 2 cps apart, centered at 1.30 (3H, diastereomeric methyl protons), a doublet (J=3 cps) at 2.25 (1H, acetylonic), a doublet (J=2 cps) at 2.60 (1H, acetylenic), a multiplet at 2.80 (1H, methine), a broad singlet at 3.50 (1H, hydroxyl, collapses with D_2O), and a multiplot at 4.50 (1H, carbinol proton), which collapsed into two overlapping sets of doublet of doublets upon shaking the sample with D_2O.

Hydrogenation of 4—methyl-1,5-hexadiyn-3-ol (86)

A 0.598 g (5.56 mmol) sample of the alcohol, in pentane over 10% Pd/C, absorbed 495 ml of hydrogen at 299°K, which corresponded to 91% of the 545 ml theoretically required to saturate two triple bonds. V.p.c. of the hydrogenated material indicated two main products. The major product (70%) had a v.p.c. retention time equal to that of authentic 4-methyl-3-hexanol on three different v.p.c. columns (2 ft SE-30, 2 ft Triton-X, and 10 ft Apiezon). The minor (30%) product had a v.p.c. retention time equal to that of authentic 4-methyl-3-hexanone on the three different v.p.c. columns.

Vapor phase thermolysis of 4-methyl-1,5-hexadiyn-3-ol (86)

This compound was thermolyzed at 370°and a pressure of 25 mm. Considerable polymerization and carbonization in the cooler regions of the thermolysis column was observed. o-Cresol was the only isolable product from the thermolyzed mixture. V.p.c. showed the cresol to be the major product of the reaction, although a lower boiling product, believed possibly to be a cyclobutenecarboxaldehyde, was also present. This product polymerized upon distillation preventing its characterization. The data follows.

A 1.41 g sample of the alcohol was thermolyzed at 370-5° and a pressure of 25 mm. The condensed product, 0.743 g (53% recovery) was dark brown and viscuous. V.p.c. analysis showed a minor (30%) and a higher boiling major (70%) volatile thermolysis product. The major product had v.p.c. retention time identical to that of authentic o-cresol, but shorter than that of authentic m-or p-cresol.

The major thermolysis product was isolated free of polymeric material by distillation under aspirator pressure. It gave an infrared spectrum superimposable on that of authentic o-cresol but different from those of m-and p-cresol. The product was converted to its dibromo derivative by the procedure of Shriner and Fuson.[60] Recrystallization from ethanol/water yielded white crystals, m.p. 53° (lit.[60]: 56°) which showed no melting point depression on admixture with an authentic sample.

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