A TOTAL SYNTHESIS OF SPIRO[BIS(2,3-DIAZABICYCLO[2.2.1]HEPT-2-ENE-7,7']

Thesis by

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To

My Mother and Father

ACKNOWLEDGEMENTS

I would like to thank the entire Dougherty group, especially Professor Dennish Dougherty and Lisa McElwe-White. Without their help, I could have never managed to accomplish this work.

ABSTRACT

The total synthesis of spiro[bis(2,3-diazabicyclo[2.2.1]-hept-2-ene)-7,7'] from trans-1,4-dibromo-2-butene was accomplished. One advantage of this synthetic route is that it can be carried out on a relatively large scale. Another advantage is that the synthesis of flexible. With a few minor modifications, one can generate various C_9H_{12} spiro ring system derivatives.

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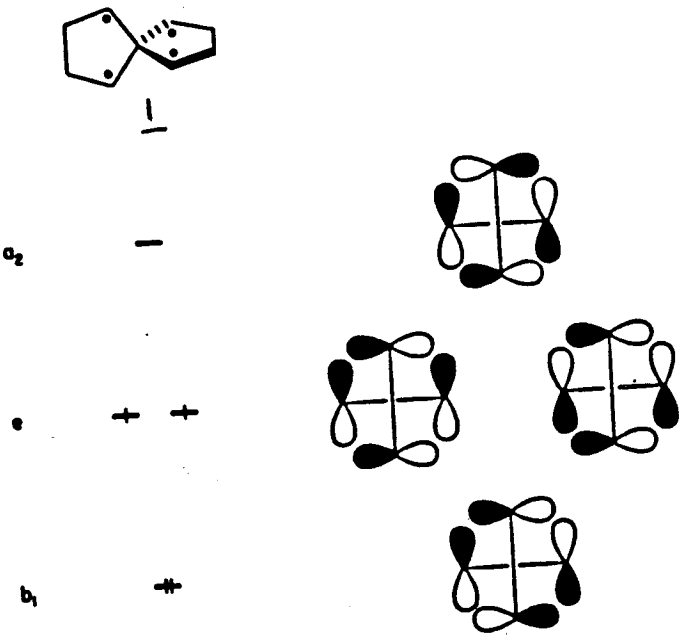
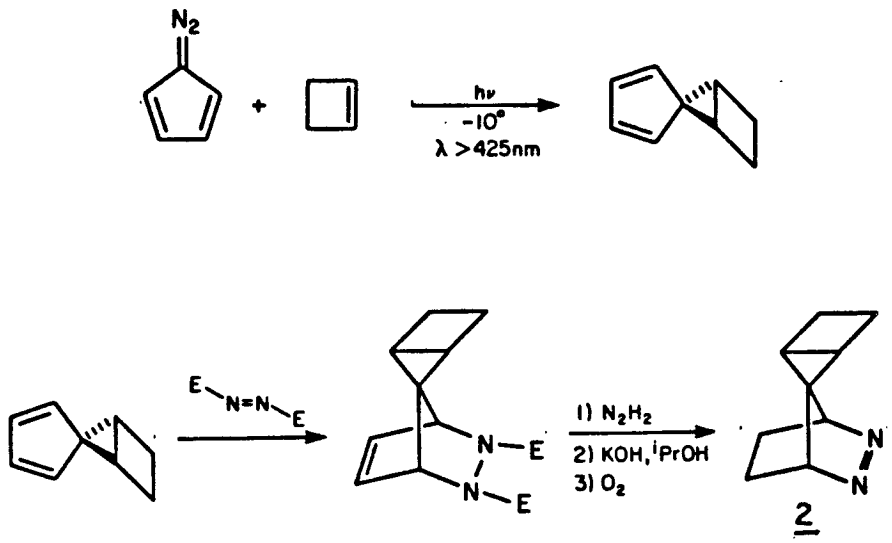
INTRODUCTION

Recently, there has been interest in the possibility of generating and characterizing 1,4,6,9-spiro[4.4]nonatetraryl 1, an organic tetraradical. The singly occupied p orbitals of 1 interact via spiroconjugation[1]. This allows 1 to have the electronic structure of a biradical (two electrons in a degenerate pair of nonbonding MO's), although 1 is, in a structural sense, a tetraradical (two broken bonds). Scheig's emperical formula for the estimation of the spiroconjugative split in spiro[4.4]nonane derivatives predicts a 1.9 eV gap between the b_1 and the a_2 molecular orbitals of 1, which has D_{2d} symmetry.[2] Ab initio calculations are fully consistent with this result.[3]



The initial studies attempting to generate the tetraradical 1 were carried out by Lisa McElwee-White and Dennis A. Dougherty on the azoalkane 2, which was synthesized as outlined in Scheme I.[4]

Scheme I



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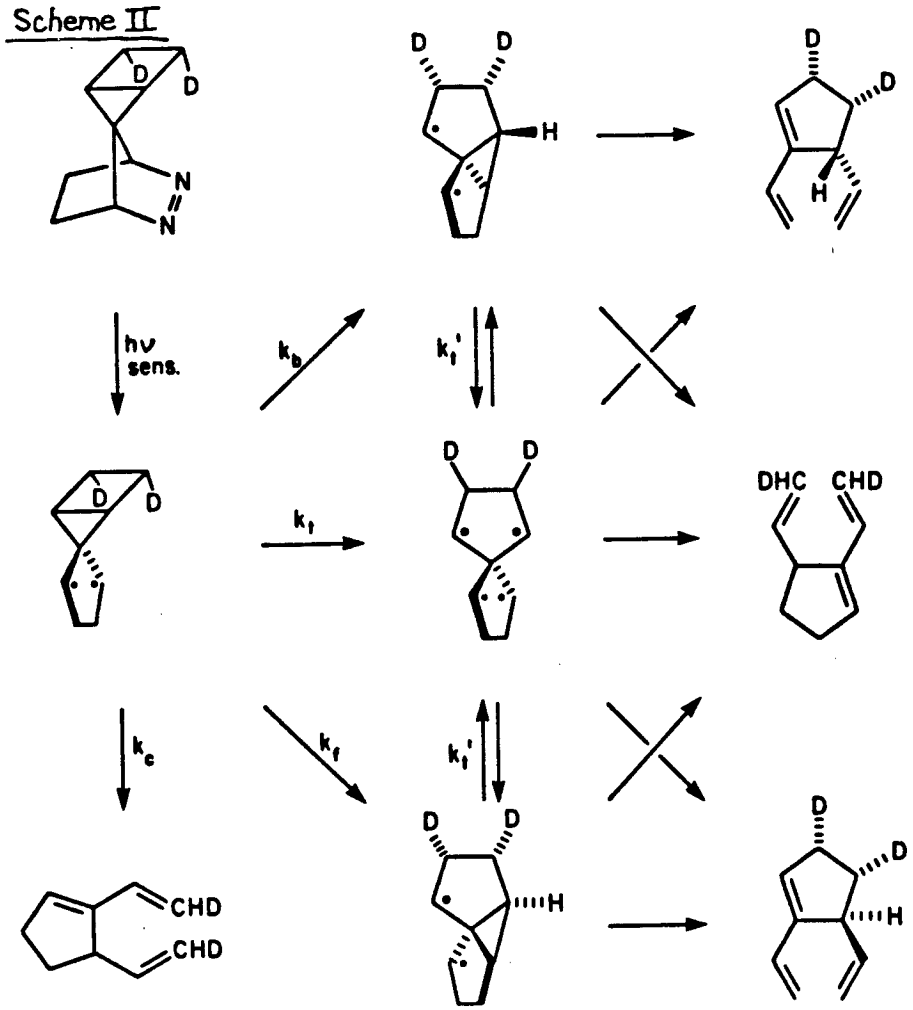
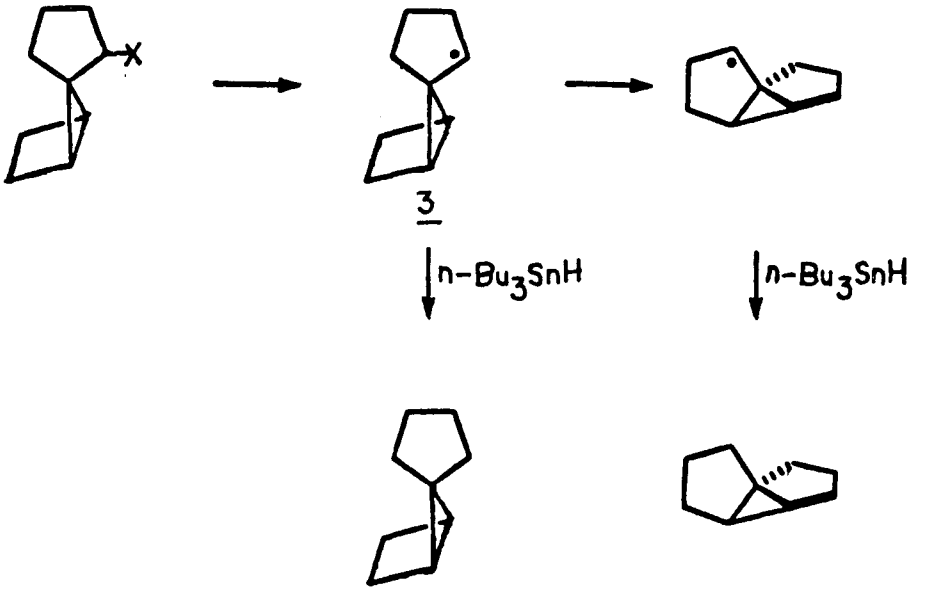
The results of the sensitized photolysis of the azoalkane 2 indicate that the best model of the reaction is as shown in Scheme II. This model of the reaction requires one of two unprecedented results: frontside radical attack on a C-C bond (k_f) or the formation of an organic tetraradical 1 (k_t or $k_{t'}$).

These results indicate that further studies of this type of system are necessary.

Scheme II

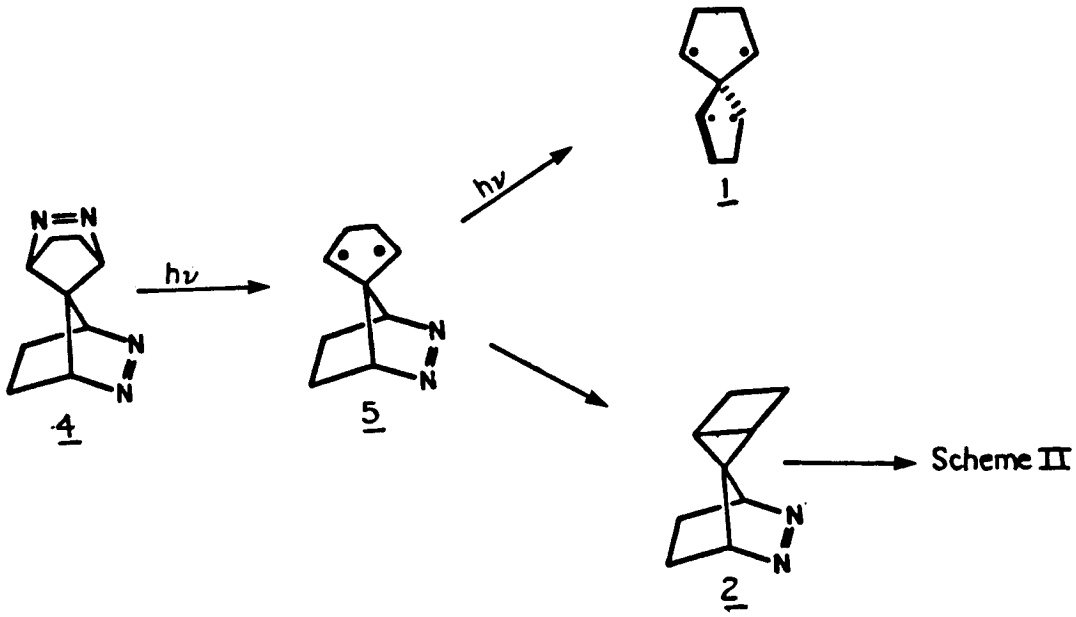


One possible way for further investigating the results of the sensitized photolysis of the azoalkane 2 would be the radical trapping studies of the mono-radical 3. This could provide further information of the viability of the frontside radical attack on the C-C bond.



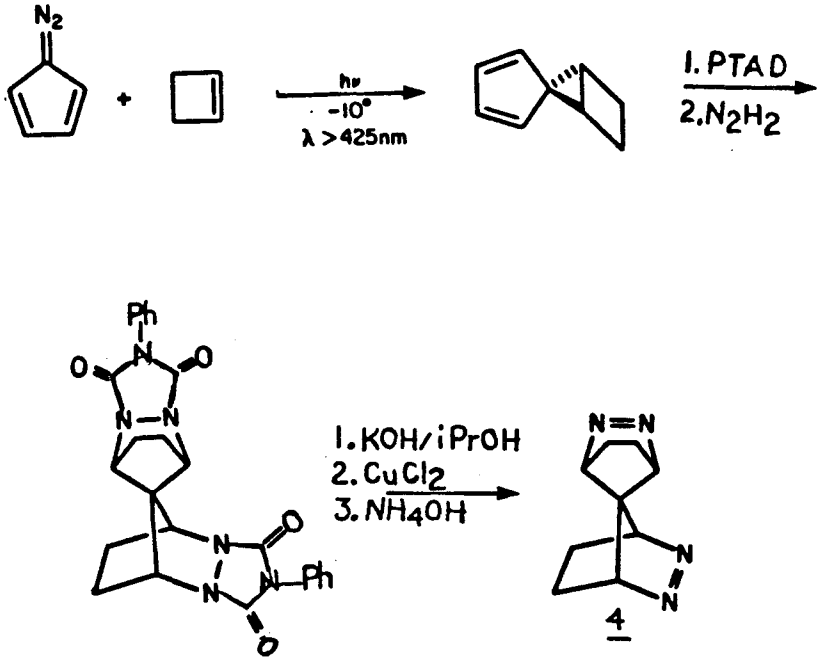
Another way to further investigate the results of the sensitized photolysis of the azoalkane 2 would be to study the decomposition of spiro[bis(2,3-diazabicyclo[2.2.1]hept-2-ene)-7,7'] (bisdiazene 4 or diazene 4). Assuming 2 photons are required to generate the tetraradical 1 from the diazene 4,

several processes are possible. The first photon would cause the expulsion of a N_2 molecule to give the biradical 5. If C-C bond formation is slow, absorption of a second photon would lead to the tetraradical 1. However, if bond formation occurs, the diazene 2 would be formed, and then it would enter into Scheme II.



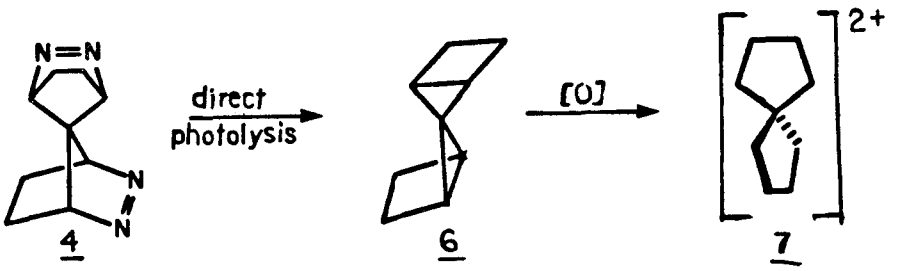
The diazene 4 was prepared by Lisa McElwee-White, as shown in Scheme III.[5] Unfortunately, the low yields of the reactions in this scheme preclude a large scale synthesis of 4.

Scheme III



Preliminary results of the studies of the diazene 4 indicate that direct photolysis of 4 leads primarily to 5,5'-spirobis(bicyclo[2.1.0]pentane)6, which in itself could be useful for studies of spiroconjugation. It follows from the orbital diagram of the tetraradical 1 that a dication obtained by chemical or electrochemical oxidation of 6 could be spiroaromatic. The charge would be distributed over a large region of space and over five carbons in addition to the spiro-conjugative stabilization; therefore,

the dication 7could be quite a stable dication. Electrochemical, 2-electron oxidation of bicyclo[2.1.0] pentane has recently been accomplished.[6] A similar experiment on 6 could lead to 7, which is expected to show interesting properties.



4 6 7

Preliminary results of the sensitized photolysis of the diazene 4 indicate that interesting reactions are occurring. A new product, different from those resulting from the sensitized photolysis of 2 has been observed.[5] This new product has not yet been identified.

Therefore, there is a need for a synthesis of the diazene 4 that would be flexible enough that only minor modifications would be needed to generate precursors to the mono-radical 3. The research described in this thesis, therefore, was directed toward the development of a large

scale synthesis of the diazene 4 which could be easily modified to produce precursors to the mono-radical 3.

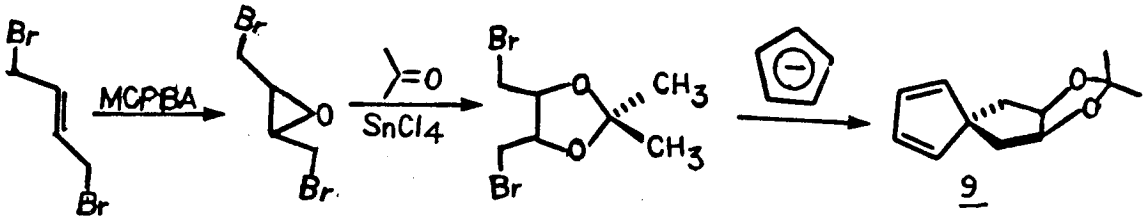
THE SYNTHESIS OF SPIRO[BIS(2,3-DIAZABICYCLO[2.2.1]HEPT-2-ENE)-7,7']

INTRODUCTION

The synthesis of spiro 4.4 nonatetraene 8 was accomplished by M.F. Semmelhack, J.S. Foos, and S. Katz.[7] While 8 is too thermally labile to be a precursor to the bisdiazene 4, the synthetic methods employed in that study are analogous to those that were proposed to be employed in the synthesis of the diazene 4. The spiro ring system construction that was proposed in the synthesis of 4 was the same construction employed by Semmelhack et. al. in their studies.

8

spiro ring system construction



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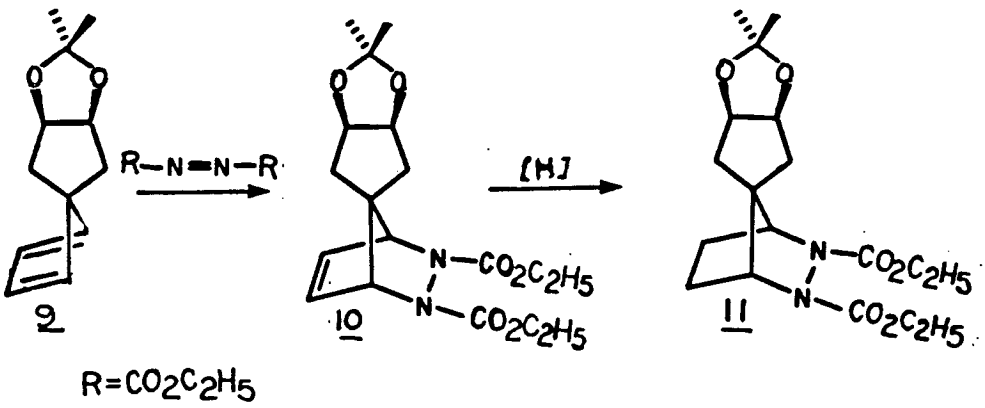
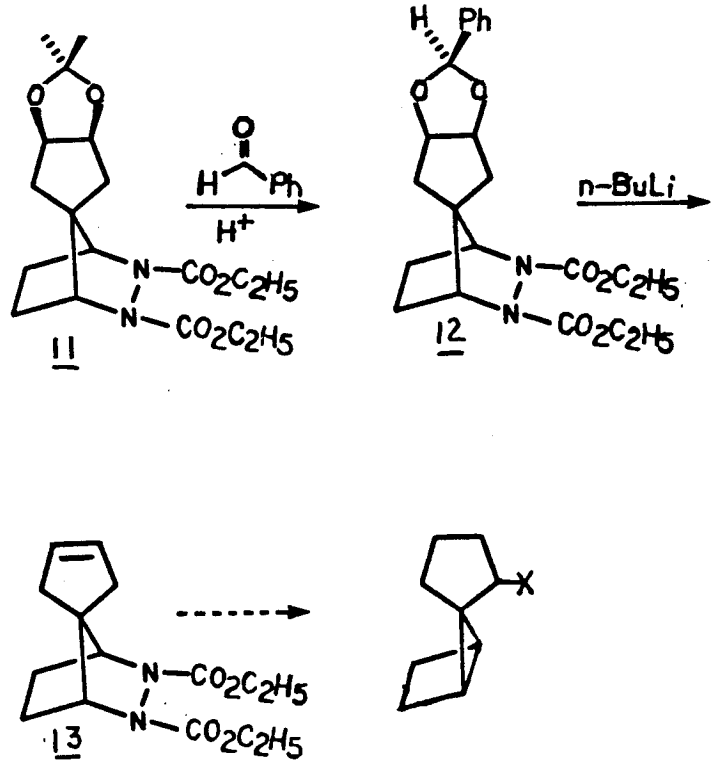
To eliminate some of the problems that Semmelhack had with spiro[4.4]nonatetraene, and to add the necessary N-N bond, it was proposed that ethyl azodicarboxylate be added in a Diels-Alder type of reaction to the diene 9 to give 10. Then one could hydrogenate 10 to give 11.

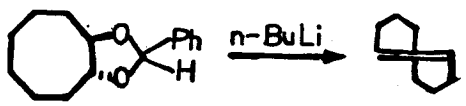


One can envision many ways to go from the compound 11 to either the diazene 4, or a precursor to the mono-radical 3. Scheme IV shows a possible route to precursors of 3.

Scheme IV



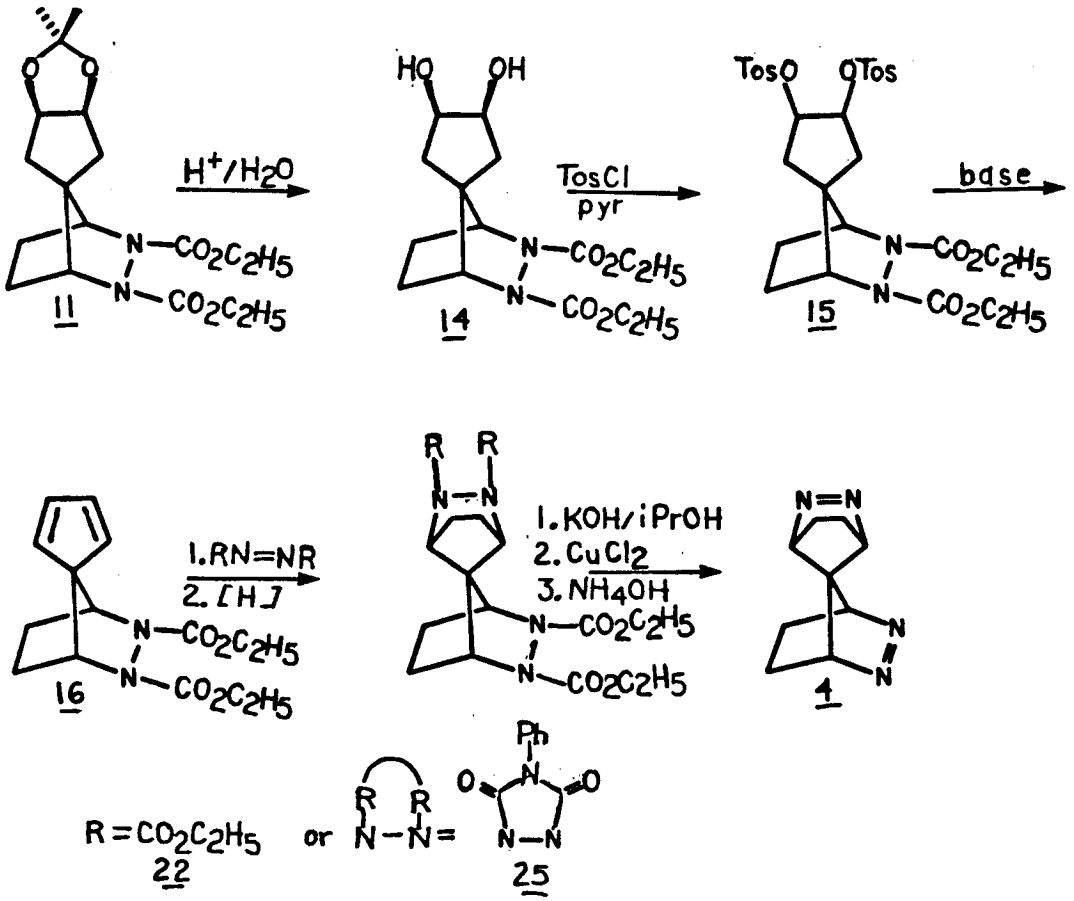
The exchange reaction of an aldehyde for a ketone, which is driven by distilling off the more volitile one, in this case acetone, is a well known reaction. The elimination reaction is analogous to the production of trans-cyclo-octene from the benzilidene derivative of trans-cyclo-octane-1,2-diol.[8]



From the mono-olefin 13, one can expect access to mono-radical 3 precursors via reactions at the allylic carbons.

Scheme V shows a possible route to the bisdiazene 4.

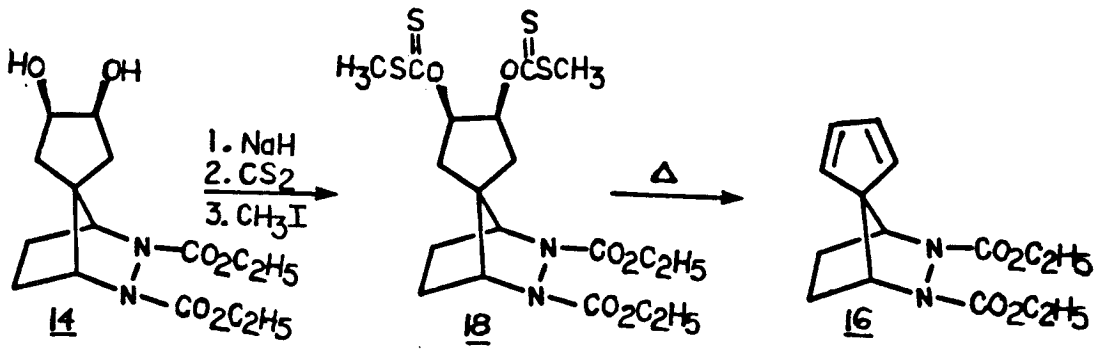
Scheme V



Hydrolysis of a ketal to a diol,[7] and the substitution of the p-toluene sulfonate for the diol hydrogen[7] are well precedented reactions. Base promoted elimination of the tosylate anion to give an olefin is also a precedented event.[9] The addition of ethyl azodicarboxylate or PTAD, and the subsequent hydrogenation of the product is the same type of reaction as seen in the last two steps of the overall synthesis that produced compound 11. The hydrolysis-oxidation of that product, 22 or 25, was accomplished on the analogous di-PTAD adduct.[5]

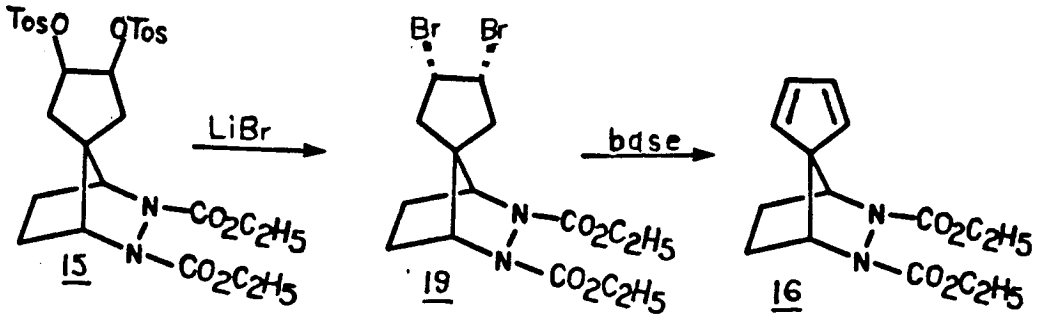
Schemes VI-IX show variations of the basic route of Scheme V.

Scheme VI

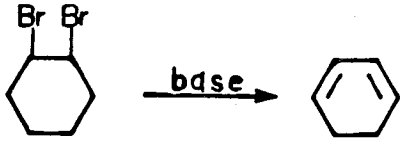


Regarding Scheme VI, the synthesis of the dixanthate by first making the dianion of the diol, then adding carbon disulfide, and then reacting that product with methyl iodide is a common method of synthesis of xanthates.[7] The cis elimination of a xanthate to an olefin, by pyrolysis, is also a common reaction.[10] The steps that would take the diene formed, 16, to the bisdiazene 4 are the same steps as outlined in Scheme V.

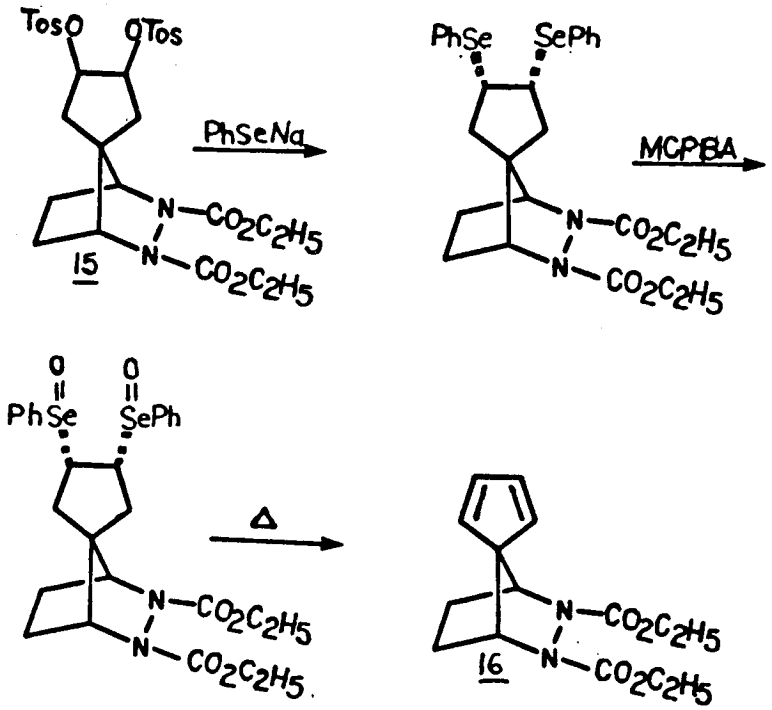
Scheme VII



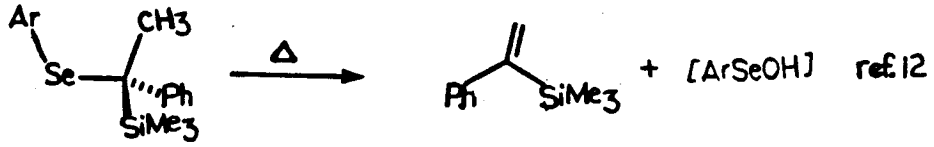
Alternatively, the bis-elimination of a 1,2-dibromide has precedence in literature,[11] and could be applied to the present system as shown in Scheme VII. The steps that would take the diene formed, 16, to the bisdiazene 4 are the same steps as outlined in Scheme V.



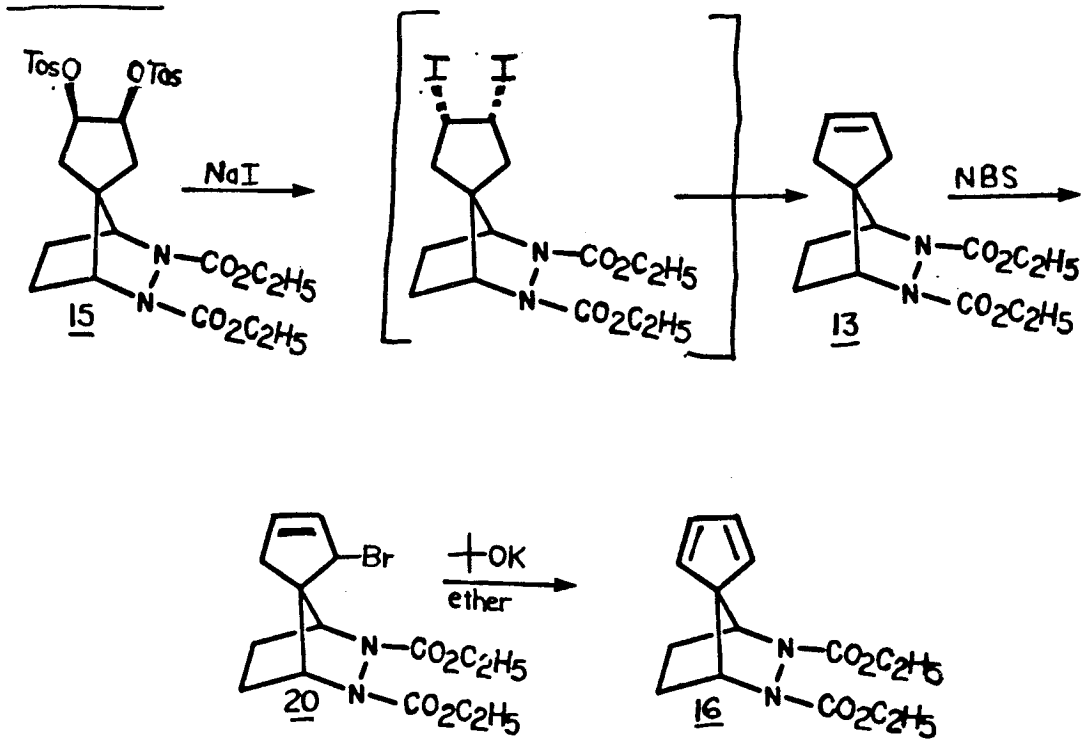
Scheme VIII



Precedence for the syn-elimination of selenoxides (Scheme VIII) can be found in the work of Hans J. Reich,[12] K.B. Sharpless,[13] and others. The steps that would take the diene formed by such an elimination of the di-selenoxide to the bisdiazene 4 are, again, the same steps as outlined in Scheme V.



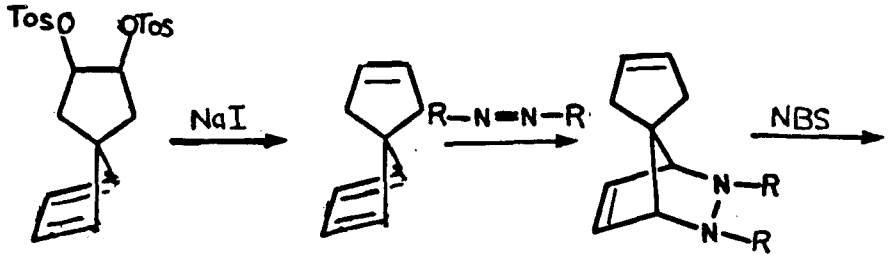
Scheme IX



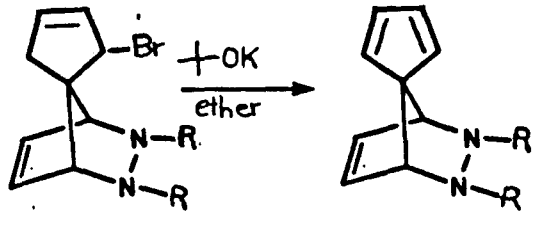
The reaction of Scheme IX, in which a di-tosylate is converted to an olefin via a di-iodide has a great deal of precedence. From the mono-olefin 13 one could go two ways. 13 is an entry into Scheme IV, which is a route to the precursors of the mono-radical 3. One could also allylically brominate 13, and then do the base promoted elimination reaction to the diene 16, which can be taken to the bisdiazene 4 as in Scheme V.

Semmelhack et. al. did a very similar series of reactions with encouraging results,[7] although his final product, a non-hydrogenated analogue of the diene 16, decomposed over a period of a few hours at room temperature.

Semmelhack :



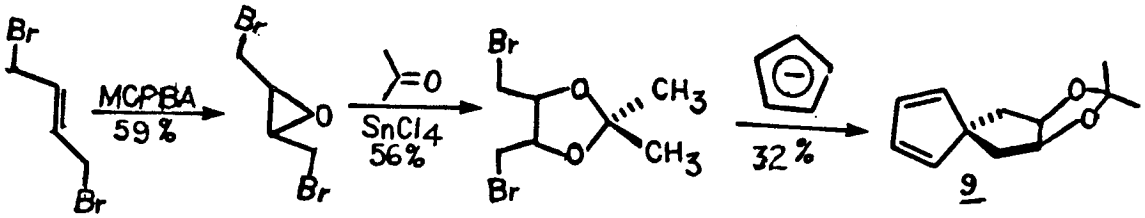
$R = CO_2CH_3$



RESULTS AND DISCUSSION

The starting point of the synthesis of the bisdiazene 4 is the readily available spiro-dioxolane 9, first synthesized by Semmelhack et. al. (Equation 1).

Equation 1

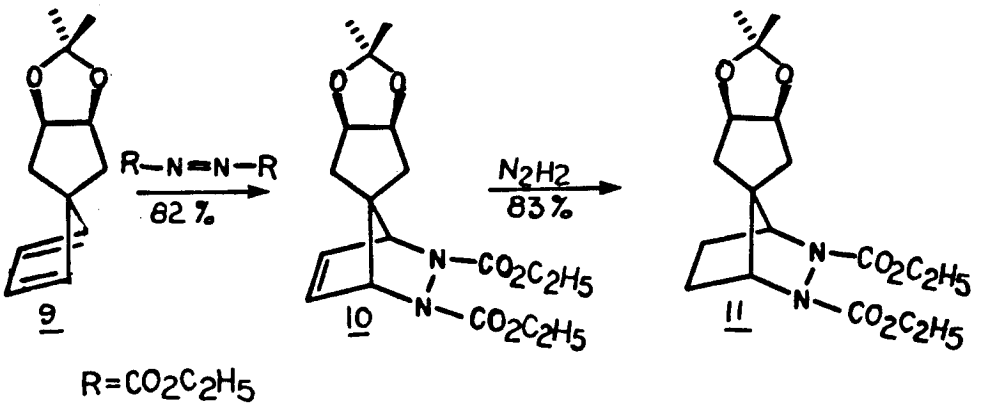


Diethyl azodicarboxylate was added in a Diels-Alder reaction to the spiro-dioxolane 9 by reaction at 55° for 47 hours in carbon tetrachloride in 82% (Equation 2). The product, diene 10, was characterized by ^{13}C NMR and PMR. The PMR showed a multiplet at 6.50 corresponding to the two vinyl protons.

Initially, catalytic hydrogenation over Pd/C with 1 atm. of H_2 was attempted. This gave only starting material. This may be due to the steric hindrance resulting from the interaction of the C=C bond to be hydrogenated and the CH_2 hydrogens on the other ring. Then the hydrogenation of the of the olefin 10 was accomplished with a diimide reduction

using $N_2H_4 \cdot H_2O$ in ethanol (Equation 2). The mixture was heated at 52° for 24 hours in 83% yield. The product 11 was characterized by ^{13}C NMR and PMR. The disappearance of vinylic protons in the PMR was noted as evidence that the reaction was successful.

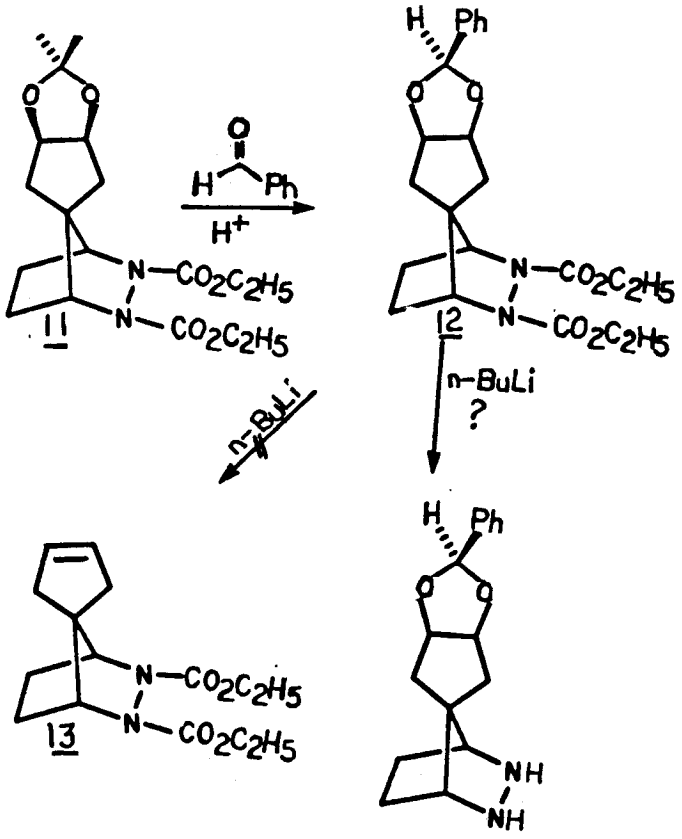
Equation 2



Initially, the synthesis of the mono-olefin 13 was attempted through the reaction of n-butyl lithium with the acetal 12, which was produced from 11 by an exchange reaction with benzaldehyde(Equation 3). The exchange reaction took place by heating 11 with benzaldehyde in carbon tetrachloride for 5 hours at 62° in a yield of 86%. When the acetal 12 was heated for 5 hours at 51° with one equivalent of n-butyl lithium, only starting material was present. When a ten fold excess of n-butyl lithium was added to the

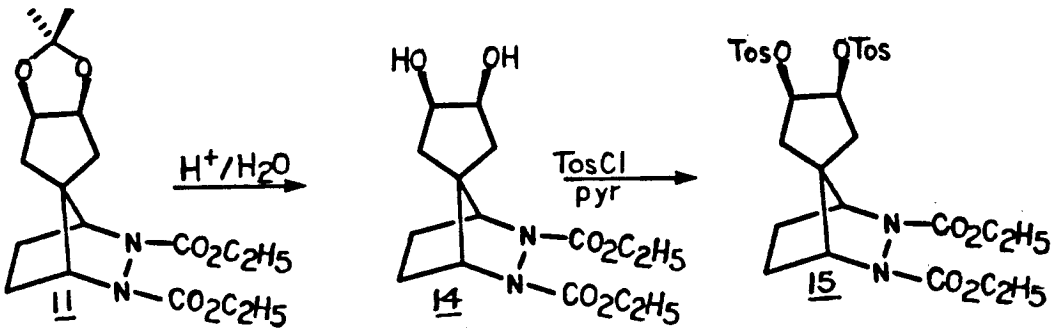
solution, the desired olefin was still not produced. Instead of removing the hydrogen on the benzalhyde acetal, the n-butyl lithium apparenly attacked the esters. The resulting product may have been the hydrazine, which would be produced upon work up. The evidence for this can be seen in the PMR. The protons on the esters are missing, the protons on the benzaldehyde acetal are still present, and there is no sign of vinylic protons.

Equation3



The next methods for the attempted preparation of the bisdiazene 4 involved elimination reactions of the spiro-di-tosylate 15, which was prepared from the diol 14. The diol 14 was prepared by the hydrolysis of the ketal 11 by heating the ketal at 92° for 45 minutes in 50% water/50% methanol with a catalytic amount of HCl (Equation 4). The yield of this reaction was 82%. The diol 14 was characterized by PMR. The spiro-di-tosylate 15 was prepared by allowing the crude diol 14, and p-toluene sulfonyl chloride to stand in pyridine at 4° for 3 days (Equation 4). The yield was 75%. The product was characterized by PMR.

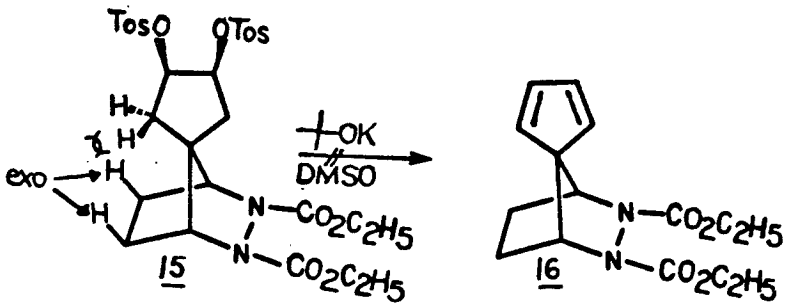
Equation 4



Initially the elimination of the spiro-di-tosylate 15 to give the diene 16 was attempted by reacting 15 with potassium tert-butoxide in dimethyl sulfoxide at 25° for 2 hours (Equation 5). This base was chosen because of its

steric bulk. No reaction was observed. Upon work up with water, the diol 14 was regenerated. One possible explaination of the lack of elimination is the steric hindrance of the exo-hydrogens and the bulky tosylates of the spiro-di-tosylate 15.

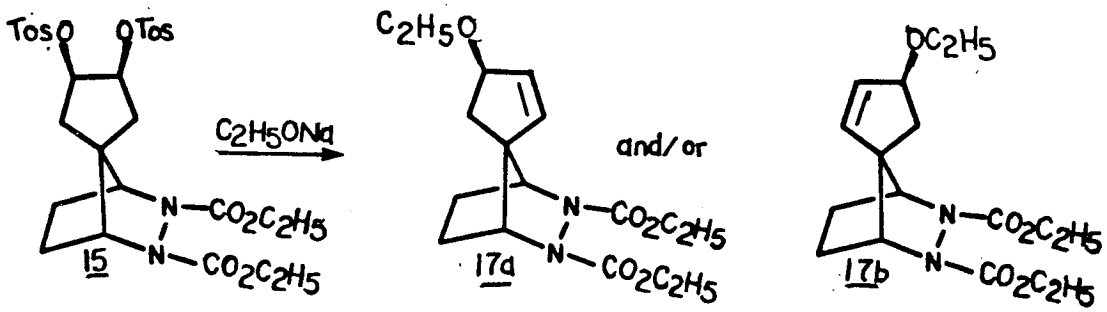
Equation 5



In view of this conclusion, the elimination reaction of the spiro-di-tosylate 15 was attempted using sodium ethoxide (Equation 6). This base is smaller, so that some of the steric problems may be overcome. The spiro-di-tosylate was heated for 23 hours at 73° in ethanol with sodium ethoxide. The product of this reaction resulted from the elimination of one side of the di-tosylate 15, and substitution of an ethoxide group on the other side, 17. The product, 17, was identified by PMR and mass spectrometry. A distinction between 17a and 17b was not possible, but

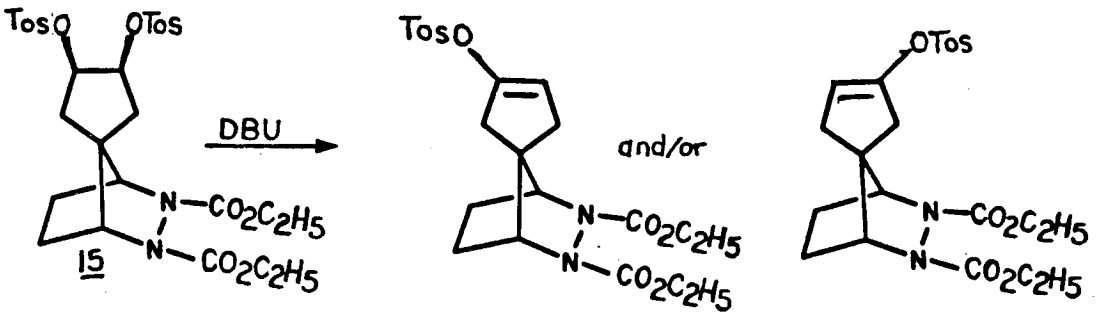
since the exo hydrogens hinder the production of 17b, it seems likely that 17a is the predominant product.

Equation 6



Attempts were made to carry out the elimination reaction of the spiro-di-tosylate 15 with more reactive, less nucleophilic, albeit, sterically bulky amide bases. The reaction of 15 with lithium diisopropyl amide (LDA) in tetrahydrofuran at room temperature for 18 hours gave only starting material back. LDA is too bulky a base for any elimination to occur. The elimination was also attempted with 1,5-diazabicyclo 5.4.0 -undec-5-ene (DBU), which was heated with 15 at 75° in benzene for 18 hours. This gave some of what appears to be the product of the elimination of the hydrogen on a carbon attached to the tosylate (Equation 7). The product was identified by PMR with olefin peaks at 4.60-5.45. The partial loss of tosylate protons was also noted.

Equation 7

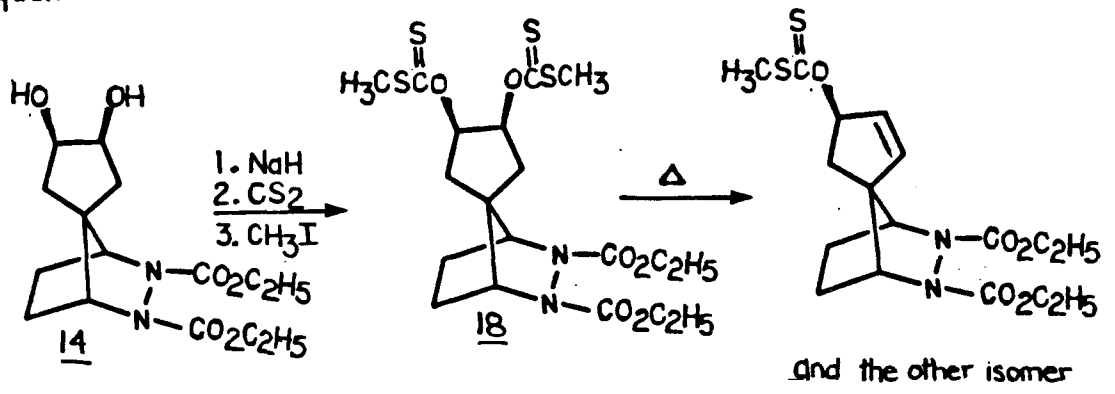


Since the elimination reactions of the spiro-di-tosylate 15 with various bases did not give the desired product, the diene 16, another approach had to be tried. One approach that was tried was the pyrolysis of the dizanthate 18. The dixanthate was prepared from the diol 14 by initially making the dianion of the diol by the reaction with NaH, then allowing that to react with CS_2 for 2 hours at room temperature, and then allowing the product of that reaction to react with CH_3I for $\frac{1}{2}$ hour at room temperature (Equation 8). The dixanthate was characterized by PMR. The yield was 75%.

The dixanthate pyrolysis was initially tried by heating the dixanthate to 130° for 4 hours under argon, and then increasing the temperature to 190° for 2 hours. The product of this reaction appeared to be some of the product of the elimination of just one of the xanthates and some starting material (Equation 8). Then the reaction was tried by

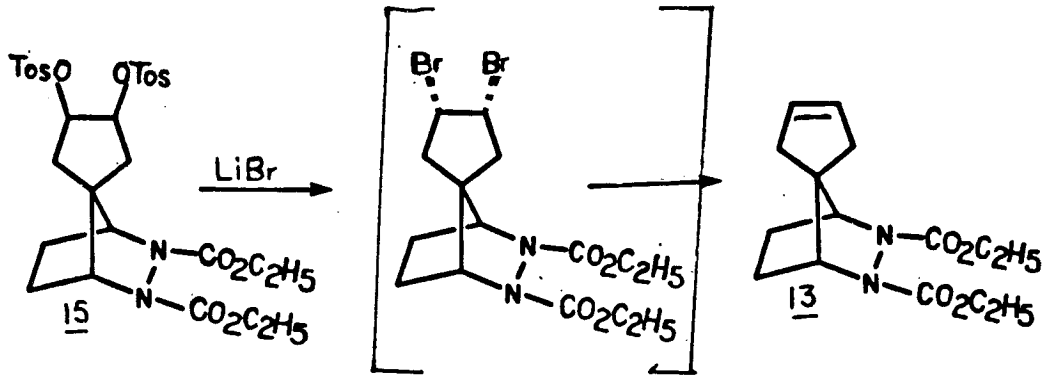
heating the dixanthate to 200° in a Kugelrohr under vacuum. What appeared to be the product of the elimination of one of the xanthates distilled over (Equation 8). This product was then heated under argon at 190° for one hour, but no further reaction occurred. The product was characterized by PMR. There was an incomplete loss of the xanthate protons, and the appearance of a multiplet due to vinylic protons at 5.35-6.20.

Equation 8



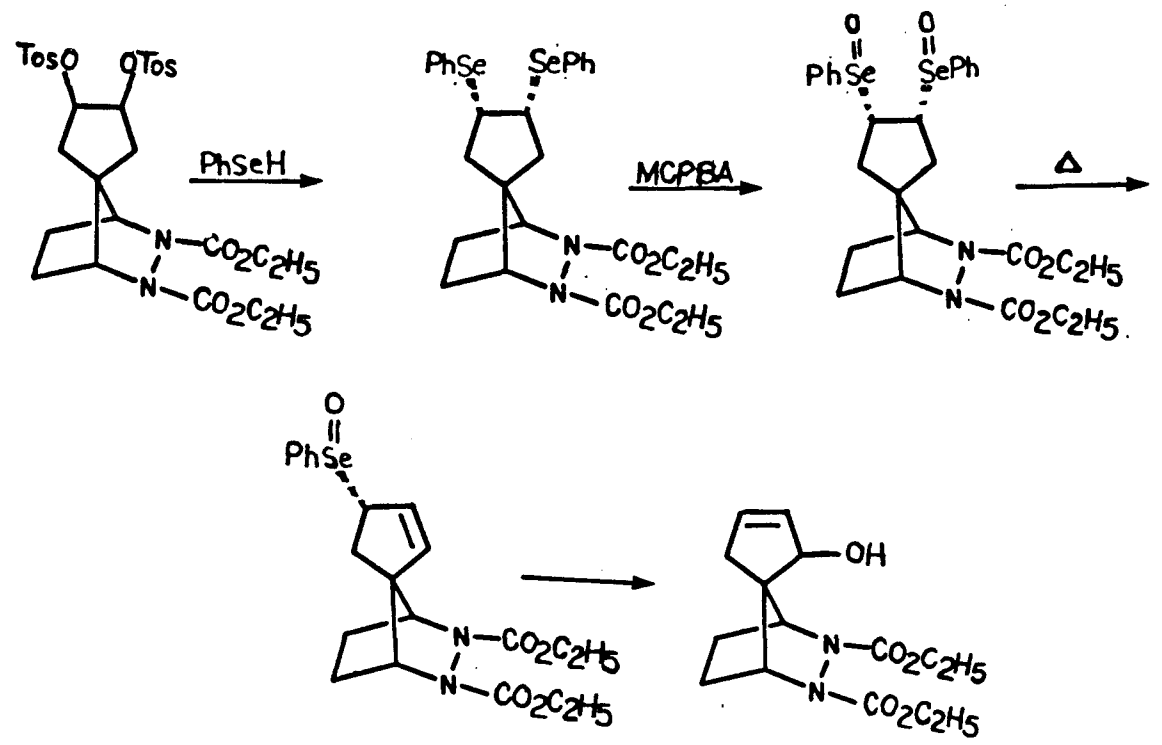
The next reaction attempted was the formation of the dibromide 19, and its subsequent elimination with base. The spiro-di-tosylate 15 was heated with LiBr in acetone for 48 hours in an attempt to make the dibromide. Apparently, once the bromide 19 was formed, it eliminated bromine to give the mono-olefin 13.(Equation 9). This reaction was characterized by PMR. Therefore, another method of generating the diene 16 was needed.

Equation 9



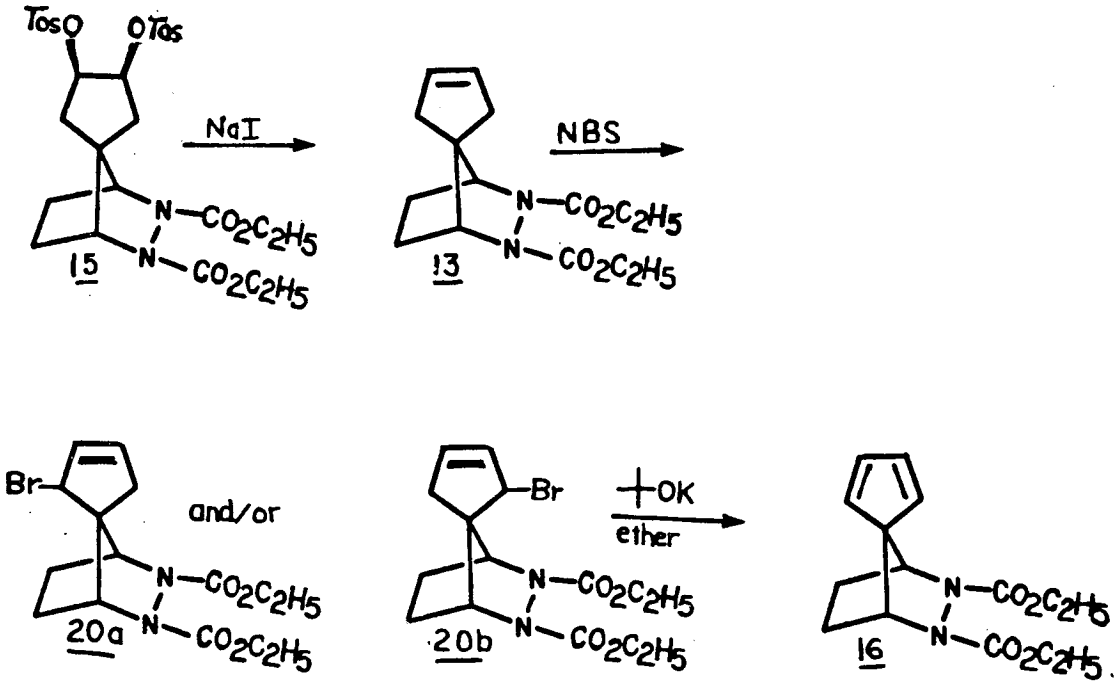
The next reaction scheme that was conceived was the elimination of a diselenoxide formed from the spiro-ditosylate 15. 15 was allowed to react with sodium phenylselenide in ethanol at room temperature for 2 hours. The product was characerized by PMR. There was a new peak at 2.22-2.42 perhaps due to CH-SePh. The yield was very low, and the diselenide was never obtained pure. At that time, a literature search revealed that allylic selenoxides normally undergo a 2,3 sigmatropic rearrangement very rapidly at low temperature to yield an allylic alcohol after solvolysis of the intermediate selenate ester (Equation 10);[14] therefore, since initiallly an allylic selenoxide would be formed in the desired transformation, this route was abandonned, without attempting any oxidations of the selenide.

Equation 10



The next procedure that was attempted, and that ultimately succeeded, was to make the mono-olefin 13 from the spiro-di-tosylate 15 (Equation 11). A solution of the spiro-di-tosylate and an excess of sodium iodide in acetone was heated for 4 days at reflux. Initially the di-iodide was formed, which then eliminated I_2 to give the mono-olefin 13 in 82% yield. This product was characterized by ^{13}C NMR, PMR, and mass spectrometry. There were 10 peaks in the ^{13}C NMR plane of symmetry of the molecule. A broad singlet was evident in the PMR at 5.60 due to the vinylic protons.

Equation II



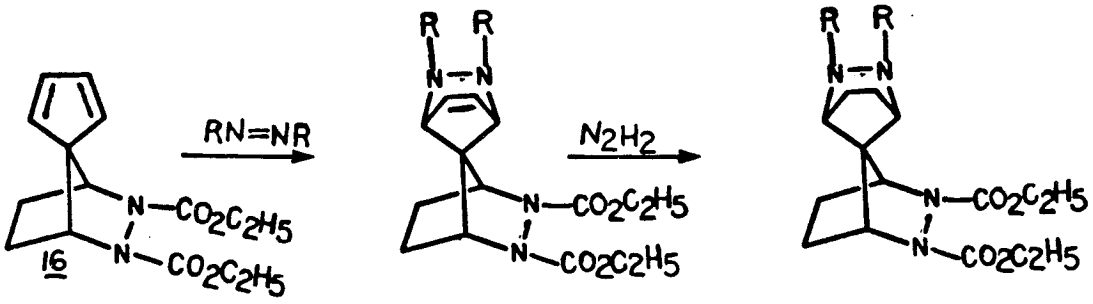
The mono-olefin 13 was then heated to reflux in carbon tetrachloride with N-bromosuccinimide and dibenzoyl peroxide (as initiator) for 2 hours to give the allylic bromide in 87% yield. This was characerized by PMR. A distinction between isomers of the allylic bromide was not possible. 20b is probably the isomer that is predominatly fromed, due to the steric hindrance of the exo hydrogens during the formation of 20a. The allylic bromide 20 is somewhat sensitive, and it turns brown upon sitting at room temperature in oxygen; therefore, the next reaction must be carried out as soon as possible.

The allylic bromide 20 is then transformed into the diene 16 by reacting with 100% excess of potassium tert-butoxide in ether for 4 hours at room temperature in 69% yield (Equation 11). The diene was characerized by PMR. It had the characeristic conjugated diene pattern from 5.95-6.50 (a pattern very similar to that of the diene 9). The diene 16 decomposes at room temperature over a period of about a day, so that any reactions with it should be carried out as soon as possible.

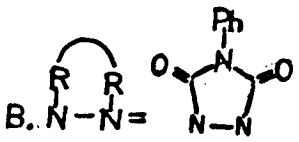
A control experiment was run with the spiro-di-tosylate 15 under conditions similar to those that made the transformation of the allylic bromide 20 to the diene 16 work. The spiro-di-tosylate was stirred at room temperature with an excess of potassium tert-butoxide in ether for 8 hours. The product of this reaction was not identified, but it was clearly not the diene 16 due to lack of vinylic protons in the PMR.

Ethyl azodicarboxylate was added in a Diels-Alder reaction to the spiro-diene 16 by heating a solution of the two reactants in carbon tetrachloride at 65° for 64 hours to produce the adduct 21 in 60% yield (Equation 12A). It seems likely that the temperature of this reaction must be greater than 64° for the reaction to proceed at a rate

Equation 12



A. R = $CO_2C_2H_5$



significantly faster than the rate at which the diene decomposes. This assumption is based on PMRs taken during the course of the reaction. The olefin peaks became broader when the temperature was below 65°. When the temperature was 65° or higher, the vinylic peak characteristic of 21 grew in. the product was characterized by PMR, with two vinylic protons at 6.57 with a similar appearance to that of compound 10.

The adduct 21 was hydrogenated by the diimide method in 85% yield (Equation 12A). Hydrazine hydrate and 21 were heated to 61° for 19 hours in ethanol with O_2 bubbled into the solution. The product was characterized by ^{13}C NMR, PMR, and mass spectrometry. The ^{13}C NMR had only a few peaks due to the C_2 axis of the molecule. The disappearance of

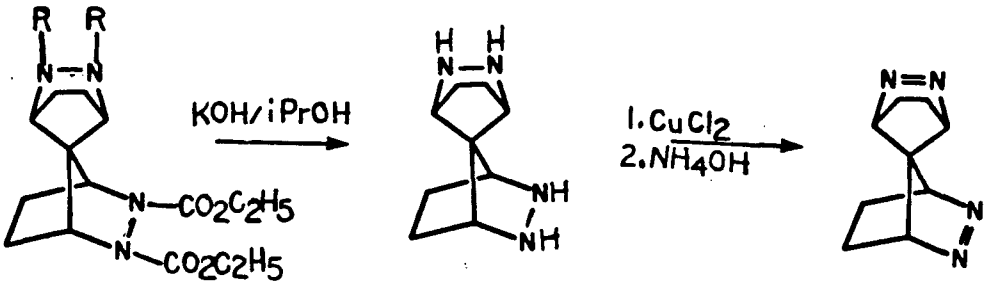
of vinylic protons in the PMR was noted as evidence that the reaction had proceeded to completion.

A variation on the last two reactions was also tried. Instead of adding ethyl azodicarboxylate to the diene 16, PTAD was added. The addition was done at room temperature over a period of a few minutes.(Equation 12B). The yield of this reaction was 96% versus 60% for the azodicarboxylate addition. The product, 24, was characerized by PMR. The PMR showed 2 vinylic protons at 6.54. The PTAD adduct 24 was then hydrogenated by the diimide reduction method.(E (Equation 12B). Hydrazine hydrate and 24 were heated to 65° for 28 hours with O_2 bubbled into the solution. The yield of the product 25 was 88%. The product was charaterized by PMR and ^{13}C NMR. The PMR showed the loss of the vinylic protons.

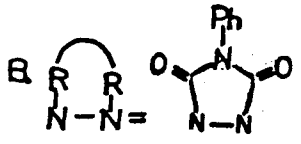
The final reactions to make the bisdiazene 4 from the hydrogenated adducts 22 and 25 were carried out in three steps (Equation 13). Initially the esters and/or the urazol were removed by reaction with KOH in refluxing isopropanol for 3 hours to produce the hydrazine 23. Then the compound 23 was oxidized by adding $CuCl_2$ to make a copper adduct, followed by the reaction of that adduct with NH_4OH to generate the bisdiazene 4. The final product was sublimed to give white crystals. The yield of the reaction

22 to 4 was 47%. The yield of the reaction 25 to 4 was 18%. The reason for the low yield of 25 to 4 was probably that the hydrazine 23 was oxidized to the diazene 4 sometime during the reaction of 25 to 23. Under these conditions, 4 would decompose once it was formed. This problem could be avoiding by very carefully excluding O_2 when one is dealing with the hydrazine 23. The product was identified by comparison of spectral data to that of the diazene 4 that was produced by the method of Lisa McElwee-White.

Equation 13



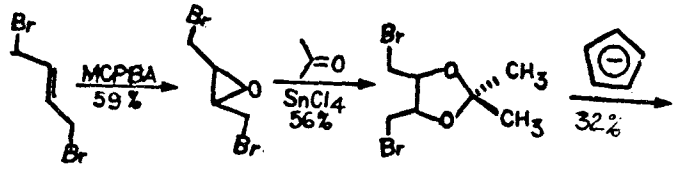
A. $R=CO_2C_2H_5$ 22 23 4

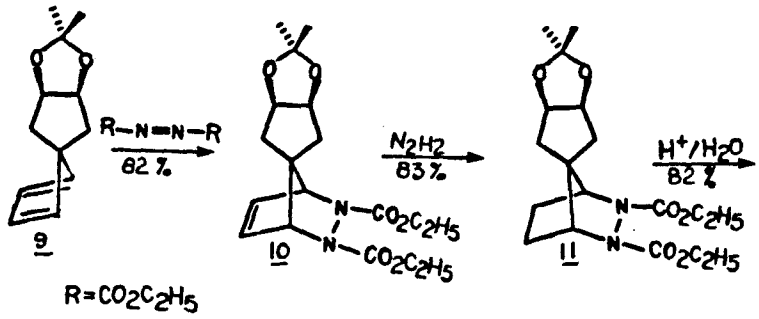


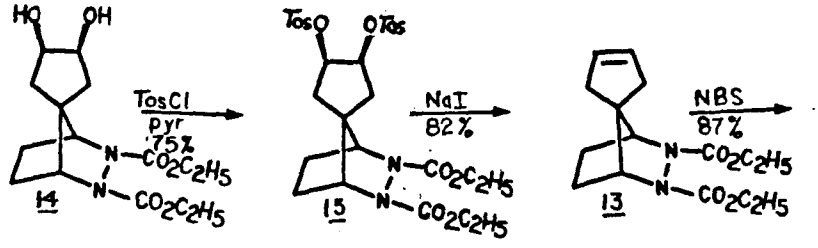
25 23 4

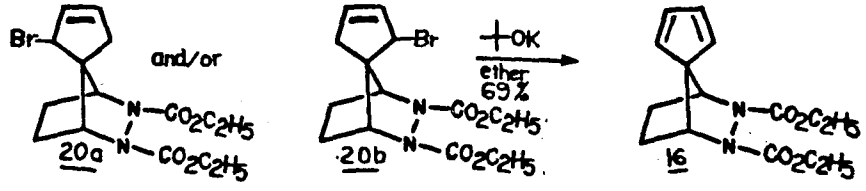
The overall yield of the synthesis from spiro-dioxolane 9 to the bisdiazene 4 was 5.1% via compound 22, and 3.1% via compound 25. The reactions are all fairly simple, which is one of the reasons that these routes to 4 are desirable.

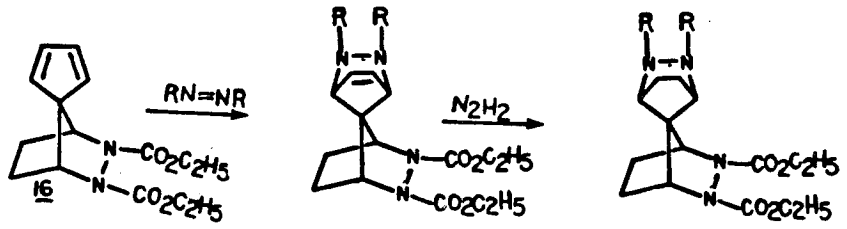
TOTAL REACTION SCHEME



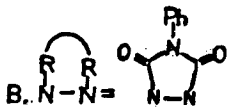


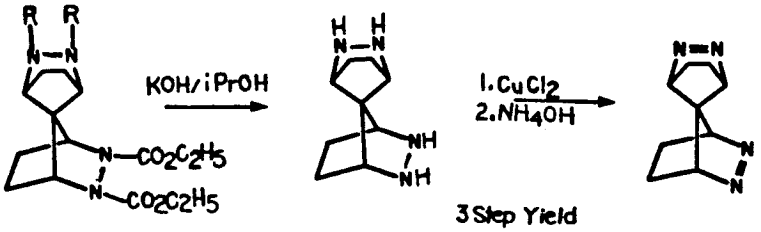






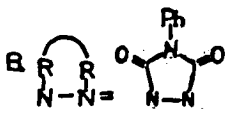
A. $R = CO_2C_2H_5$ 60% 21 88% 22

B.  96% 24 88% 25

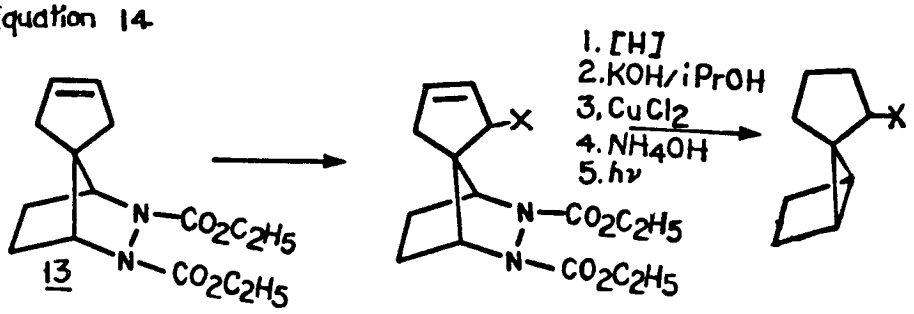


3 Step Yield

A. $R = CO_2C_2H_5$ 22 23 47% 4

B.  25 23 18% 4

Equation 14



The direct photolysis of the bisdiazene 4 produces mainly 5,5'-spirobis(bicyclo 2.1.0 pentane) 6, which may have interesting electrochemical properties (Equation 15). One might be able to generate the dication 7, which is analogous to the tetraradical 1, but would have a closed shell electronic structure. This could be accomplished by electrochemical reactions of 6.

Another possible way to generate the dication 7 would be the reaction of the dibromide 26 with magic acid ((SbF_5) (Equation 15). The dibromide 26 could perhaps be produced by allowing the allylic bromination of the mono-olefin 13 to proceed on both allylic positions. Then one could hydrogenate that product, hydrolyze the esters, and oxidize to give a dibromo-diazene. The direct photolysis of that product could yield the dibromide 26.

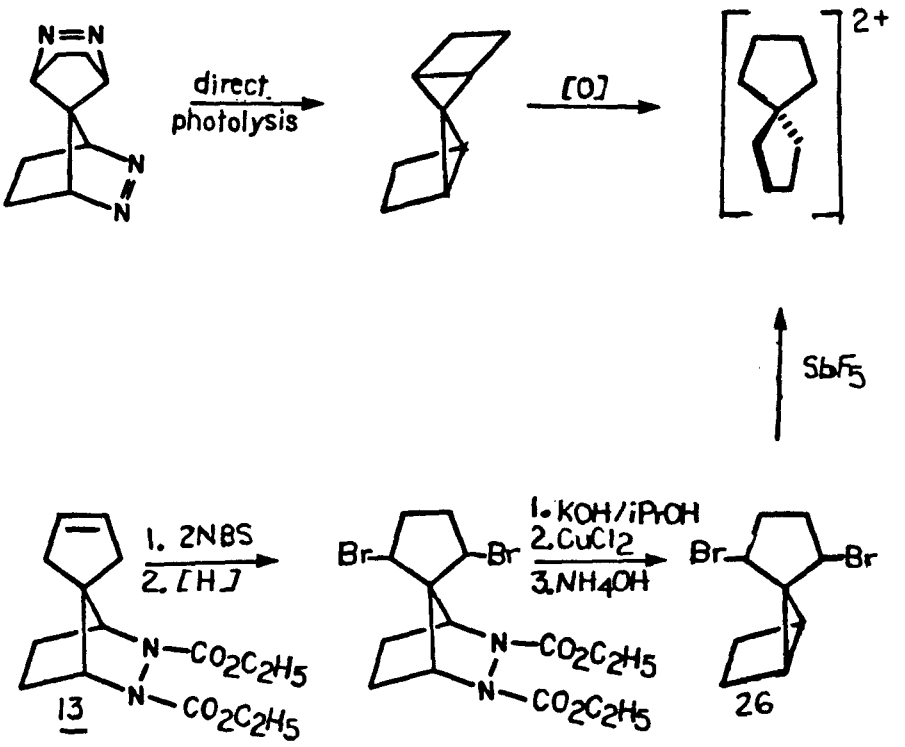
CONCLUSION

The results of these experiments are not only useful from the standpoint that the reaction scheme produces the bisdiazene 4 in relatively large quantities, but also from the standpoint of the versatility of the route.

The best method of synthesis of the bisdiazene 4 would be to add PTAD instead of diethyl azodicarboxylate in both of the Diels-Alder reaction steps. This is due to the high yield of the hydrolysis/oxidation of the di-PTAD adduct, which was initially produced in Lisa McElwee-White's synthesis of the bisdiazene 4 (Scheme III). That reaction goes in a yield of about 90%.[5] The yields of the other reactions involved would probably be relatively unchanged by the substitution of PTAD for diethyl azodicarboxylate.

One could generate the precursors to the mono-radical 3 for studies of the frontside radical attack on a C-C bond (Equation 14) with only minor modifications of the synthesis of the bisdiazene 4. This could be accomplished via reactions at the allylic positions of the mono-olefin 13. Then one could hydrogenate, do the hydrolysis/ oxidation reaction, and then photolyze to yield the desired compound (Equation 14).

Equation 15


N=N
direct
photolysis
[O]
2+
SbF5
1. 2NBS
2. [H]
N—CO2C2H5
N—CO2C2H5
13
1. KOH/iPrOH
2. CuCl2
3. NH4OH
Br
Br
Br
Br
N—CO2C2H5
N—CO2C2H5
26

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EXPERIMENTAL SECTION

General Experimental Procedures. All solvents used were ACS grade except for ethanol (absolute ethanol was used). All were not further purified except for tetrahydrofuran (freshly distilled from lithium aluminum hydride), and acetone (dried over 4 A molecular sieves). Boiling points are uncorrected. PMR spectra were obtained using a Varian EM-390 spectrometer. ^{13}C NMR data was obtained using a JEOL FX-90Q spectrometer. Mass spectral data was obtained through the aid of the Caltech Analytical Facility. All NMR chemical shifts are expressed in parts per million downfield from internal tetramethylsilane.

Preparation of trans-2,3-Di(bromomethyl)oxirane. Synthesized in 59% yield from trans-1,4-Dibromo-2-butene according to the method of reference 7.

Preparation of cis-4,5-Di(bromomethyl)-2,2-dimethyl-1,3-dioxolane. Synthesized in 56% yield from trans-2,3-Di(bromomethyl)oxirane according to the method of reference 7.

Preparation of Spirodioxolane 9. Synthesized according to the method of reference 7 with slight modifications. In a 1-liter three-neck flask fitted with two addition funnels (capped with serum caps) and a reflux condensor (capped with

a stopcock) was placed a suspension of sodium hydride (19.02g of a 60% suspension in mineral oil, 476mmol, Alfa) in 300ml of tetrahydrofuran. In the addition funnel, a solution of cis-1,4-di(bromomethyl)-2,2-dimethyl-1,3-dioxolane (52.89g, 184mmol, containing approximately 29% of the trans isomer) in 60 ml of tetrahydrofuran was placed. In the other addition funnel, 60ml of tetrahydrofuran was placed. After placing the sytem under argon, cyclopentadiene (16.94ml, 257 mmol, freshly prepared by cracking dicyclopentadiene) was injected into the addition funnel containing only tetrahydrofuran. Then the solutions were added to the sodium hydride suspension over 35 minutes at 25°. Spontaneous heating occurred. During this time, the color of the solution went from beige to purple to dark blue to black. After the addition was completed, another 1.75 ml of cyclopentadiene (72mmol) was added all at once. The mixture was allowed to stir at room temperature for 2 hours. Then water and ether were added, and the organic layer was washed with water, dried with magnesium sulfate, and concentrated by rotary evaporation. The product was purified by distillation on a Kugelrohr at a pressure of .05 torr and a temperature of 60°-110°. The yield was 11.53g (60mmol, 32%) of a clear green liquid that was slightly impure. The product was identified by comparison to that prepared by Semmelhack et. al..

Preparation of the Diels-Alder Adduct 10 of Diethyl Azodicarboxylate to Spirodioxolane 9. A solution of the spirodioxolane 9 (11.53g, 60mmol) and diethyl azodicarboxylate (11.59g, 67mmol, Aldrich Chemical Co.) in 150 ml of carbon tetrachloride was placed in a 250 ml round bottom flask fitted with a reflux condenser. This was heated to 55° for 47 hours under nitrogen. The solution, now much less yellow than it was initially, was filtered through basic alumina with dichloromethane as eluant, and then concentrated to give 18.08g (49mmol, 82% yield) of a very viscous, very light green liquid. This was characterized by PMR and ^{13}C NMR. PMR ($CDCl_3$): 1.27 (triplet with a high center, 9H, 1 ketal CH_3 and 2 ester CH_3's), 1.52 (singlet, 3H, 1 ketal CH_3), 1.73 (multiplet, 4H, 2 CH_2's near ketal), 4.17 (quartet, 5H, 2 CH_2's on esters and 1 bridgehead H), 4.53 (multiplet, 2H, 2 CH-O), 5.07 (broad singlet, 1H, 1 bridgehead H), 6.50 (multiplet, 2H, vinylic H's). ^{13}C NMR ($CDCl_3$): 14.29 (2 CH_3's on esters), 23.39 (CH_3 on ketal), 26.12 (CH_3 on ketal), 36.12 (CH_2 near ketal), 36.90 (CH_2 near ketal), 62.12 (CH_2 on ester), 62.25 (CH_2 on ester), 67.45 (bridgehead C), 68.81 (bridgehead C), 71.35 (spiro-C), 79.27 (CH near ketal), 80.05 (CH near ketal), 109.23 (C_{-O}^{-O}), 134.77 (vinylic C), 137.43 (vinylic C), 158.10 (-C-OEt), 158.69 (-C-OEt).

Attempted Catalytic Hydrogenation of the Diels-Alder Adduct 10. The adduct 10 (1.21g, 3.31×10^{-3}mol) was placed in ethyl acetate with a catalytic amount of palladium on carbon. The mixture was subject to hydrogenation in a one-atmosphere hydrogenation apparatus. Only starting material was recovered as verified by PMR.

Diimide Reduction of the Diels-Alder Adduct 10. A solution of the adduct (18.08g, 49mmol) and hydrazine hydrate (25ml, 515 mmol, Matheson, Coleman and Bell Chemical Co.) in 55 ml of ethanol was placed in a 100ml round bottom flask equipped with a reflux condenser. The solution was stirred at 52° for 24 hours while O_2 was bubbled into it. Then the ethanol was removed by rotary evaporation. The residue was taken up in diethyl ether and washed three times with water until the pH was neutral. The organic layer was dried with magnesium sulfate, and concentrated. The yield was 15.08g (41mmol, 83%) of a white solid. The product was characterized by PMR and ^{13}C NMR. PMR ($CDCl_3$): 1.27 (triplet with a high center, 9H, 2 CH_3's of esters and 1 CH_3 of ketal), 1.47 (singlet, 3H, 1 CH_3 of ketal), 1.60-2.00 (multiplet, 8H, CH_2's not on esters), 3.93 (broad singlet, 1H, bridgehead H), 4.15 (quartet, 2H, 1 CH_2 on ester), 4.17 (quartet, 2H, 1 CH_2 on ester), 4.50 (broad singlet, 1H, bridgehead H), 4.60 (multiplet, 2H, 2 CH-O). ^{13}C NMR ($CDCl_3$): 14.49 (CH_3's on esters),

23.53 (CH_3 on ketal), 26.29 (CH_3 on ketal), 27.23 (2 peaks-both CH_2's resulting from hydrogenation), 35.03 (CH_2 near ketal), 35.68 (CH_2 near ketal), 57.77 (bridgehead C), 58.10 (bridgehead C), 62.13 (CH_2 on ester), 62.26 (CH_2 on ester), 64.53 and 67.58 (one is probably due to spiro-C), 79.87 (CH-O), 80.06 (CH-O), 109.44 ($\overset{O}{\underset{O}{}}C$), 157.40 (broad, both C-OEt).

Benzaldehyde Exchange Reaction with Hydrogenation Product 11. A solution of the hydrogenation product 11 (.36g, 9.7×10^{-4}mol), benzaldehyde (.108 ml, 1.06×10^{-3}mol), and 7×10^{-6}l of concentrated HCl in 7 ml of carbon tetrachloride was placed in a round bottom flask. The reaction mixture was stirred at 62° for 5 hours allowing vapors to escape slowly. Then water was added. The organic layer was separated off, washed with water until the pH was neutral, and then concentrated. The yield was .35g (8.49×10^{-4}mol, 86%) of a white solid 12. The product was characterized by PMR. PMR ($CDCl_3$): 1.1 (triplet, 6H, CH_3's of esters), 1.5 (multiplet, 8H, CH_2's not on esters), 3.7-4.1 (multiplet, 5H, both CH_2's of esters and 1 bridgehead H), 4.1-4.8 (multiplet, 3H, 2 CH-O and 1 bridgehead H), 7.0-7.5 (multiplet, 4H, phenyl H's), 7.5-8.0 (multiplet, 1H, phenyl H).

Attempted Elimination of Benzaldehyde Product 12. A solution of 12 (.35g, 8.4×10^{-4}mol) and 525×10^{-6}liters of n-butyl lithium (1.6M in hexane, 8.4×10^{-4}mol) in benzene was put in a two-neck flask under nitrogen. The flask was equipped with a reflux condenser. The solution was stirred at 51° for 5 hours. Then water was added, and the organic layer was separated off and concentrated. The PMR indicated only starting material was present. Then the .17g (4.1×10^{-4}mol) of starting material left was put in benzene. 2.5ml (4×10^{-3}mol) of n-butyl lithium was added. After 10 seconds the solution turned orange, and then it turned yellow. The reaction was quenched with water immediately. The PMR indicated that the esters were not present, but the benzaldehyde part was still there. PMR (CCl_4): 1.32 (broad singlet, t-butanol), 3.7-4.1 (broad, about 1H, bridgehead H), 4.3-4.9 (multiplet, 3H, CH-O and a bridgehead), 7.0-7.5 (multiplet, 5H, phenyl H's).

Preparation of the Diol 14 from the Hydrogenated Adduct 11. A solution of the Diels-Alder hydrogenated adduct 11 (12.25g, 33mmol), 91 ml of water, 91 ml of methanol, and 1 ml of concentrated HCl was heated at 92° for 45 minutes in an open flask from which vapors were allowed to escape slowly. The mixture was allowed to cool. It was partitioned between dichloromethane and water. The organic layer was dried and concentrated to give 8.92g (27mmol, 82%) of the crude diol. This was not further purified.

The product was characterized by PMR ($CDCl_3$): 1.26 (triplet, 6H, both CH_3's of esters), 1.46-1.93 (multiplet, 8H, CH_2's other than on esters), 2.37-2.83 (multiplet, 2H, OH's), 3.90-4.37 (multiplet, 8H, 2 CH_2's of the esters, 2 bridge-head H's, and 2 CH-O's).

Preparation of the Spiro-di-tosylate 15 from the Diol 14. The crude diol 14 (8.92g, 27mmol) and p-toluene sulfonyl chloride (21.40g, 107 mmol, Aldrich) were dissolved in 70 ml of pyridine, and allowed to stand in the refrigerator at 4° for 3 days. A white solid precipitated out with time (the pyridine-HCl salt). The mixture was poured into ice-water and extracted 3 times with dichloromethane. This was then concentrated. The product was an orange viscous liquid. This was taken up in ether, and decanted, leaving an orange residue. The residue was taken up in dichloromethane, and filtered through Florisil. Both the ether extract and the product of the filtration were concentrated, yielding 12.62g of a white solid (20mmol, 75%). The spiro-di-tosylate was characterized by PMR ($CDCl_3$):

1.18 (triplet, 3H, CH_3 on an ester), 1.22 (triplet, 3H, CH_3 on an ester), 1.43-2.23 (multiplet, 8H, CH_2's not on esters), 2.40 (singlet, 6H, CH_3's on the tosylates),

3.87-4.40 (multiplet, 6H, CH_2's on the esters, and the bridgehead H's), 4.53-4.90 (multiplet, 2H, CH-OTos), 7.13-7.40 (doublet, 4H, tosylate H's), 7.40-7.54 (doublet, 4H, tosylate H's).

Attempted Elimination of the Spiro-di-tosylate 15 with Potassium tert-Butoxide in Dimethyl Sulfoxide.
A solution of the spiroditosylate 15 (.10g, 1.6×10^{-4}mol) in .2 ml of deuterated dimethyl sulfoxide was added via syringe to an NMR tube containing potassium tert-butoxide (.04g, 3.6×10^{-4}mol, MCB Chemical Co.) in .2 ml deuterated dimethyl sulfoxide. The reaction proceed for 2 hours at room temperature. The reaction was watched by PMR. No reaction was evident by PMR, although the solution changed from colorless to black. After 2 hours the mixture was poured into water, and extracted with hexane. The hexane extract contained the diol 14, as verified by PMR.

The Elimination Reaction of Spiro-di-tosylate 15 with Sodium Ethoxide. Sodium ethoxide was made by adding metalic sodium to ethanol (enough sodium was added for a large excess of sodium ethoxide for the next part of the reaction) in a two-neck flask equipped with a reflux

condenser and an addition funnel. The entire set up was under argon. The addition funnel contained the spiro-di-tosylate 15 (.10g, 1.6×10^{-4}mol) in .50 ml of ethanol. This solution was then added to the sodium ethoxide solution. The reaction was stirred at 73° for 23 hours. The solution became orange, and a solid precipitated out. Then most of the ethanol was removed by rotary evaporation. 2% NH_4Cl solution was added. This was then extracted with dichloromethane, and then with ether. The organic layers were combined, dried with magnesium sulfate, and concentrated. The crude product was run through basic alumina with carbon tetrachloride, and then with dichloromethane. The product was in the dichloromethane layer. There was .02g (6.1×10^{-5}mol, 38% yield) of a yellow liquid, that was identified as compound 17. The product was characterized by PMR and mass spectrometry. PMR ($CDCl_3$): 1.17 (triplet ,3H, CH_3 of ether), 1.33 (triplet, 6H, CH_3 of esters), 1.87 (multiplet, 6H, CH_2's not on esters or ether), 3.40 (quartet, 2H, ether CH_2), 3.60-4.50 (multiplet, 7H, CH_2's on esters, bridgehead H's, and CH-OEt), 5.63 (doublet, 1H vinylic H), 5.98 (doublet, 1H, vinylic H). Mass spectral mol. wt. 338.1836 (calc. 338.1840).

Attempted Elimination of the Spiro-di-tosylate 15 with Lithium Diisopropyl Amide. A solution of diisopropyl amine (.02ml, 2.0×10^{-4}mol, MCB Chemical Co.) in .5 ml of tetrahydrofuran was placed in a 10 ml two-neck flask (capped with a serum cap) equipped with an addition funnel containing the ditosylate 15 (.1g, 1.6×10^{-4}mol) in .5 ml of tetrahydrofuran, and a condenser with an argon inlet. The diisopropyl amine solution was kept at -78°. N-butyl lithium (1.6 M in hexane, .01ml, 1.6×10^{-4}mol) was added to the diisopropyl amine. After 10 minutes the spiroditosylate 15 was added, and the reaction was stirred for 20 minutes at -78°. Then more diisopropyl amide(1.6×10^{-4}mol) was added. The temperature was raised to room temperature. There was no visible change after stirring under argon for 18 hours. The reaction was heated to 35° for 10 minutes. Then ice was added, and the solution extracted with ether. The organic layer was concentrated. The PMR indicated that only starting material was present.

Attempted Elimination Reaction of the Spiro-di-tosylate 15 with 1,5-Diazabicyclo 5.4.0 undec-5-ene. A solution of the spiro-di-tosylate 15 (.10g, 1.6×10^{-4}mol) and 1,5-diazabicyclo-5.4.0 undec-5-ene (.05ml, 4.0×10^{-4}mol, Aldrich) in 1 ml of benzene was placed in a 10 ml two-neck flask equipped with

reflux condenser. The reaction was stirred at 75° for 18 hours under nitrogen. Then ice was added. The solution was extracted with ether. The ether layer was washed with water until neutral, dried with magnesium sulfate, and concentrated. The yield was .06g. The PMR indicates that the product is proabably the elimination between the tosylates, which leaves one tosylate on the molecule. PMR ($CDCl_3$): 1.23 (triplet, 6H, ester CH_3's), 1.43-2.00 (broad singlet, 6H, CH_2's), 2.20-2.50 (multiplet, 2H, allylic CH_2), 2.42 (singlet, 3H, CH_3on tosylate), 3.70-4.30 (multiplet, 6H, ester CH_2's and bridgehead H's), 4.60-4.90 (multiplet, ½H, vinylic H), 5.10-5.45 (multiplet, ½H, vinylic H), 7.20-7.50 (multiplet, 2H, tosylate H's), 7.55-7.95 (multiplet, 2H, tosylate H's).

Preparation of the Dixanthate 18 from the Diol 14. A solution of sodium hydride (.05g, 1.25×10^{-3}mol, in 60% in mineral oil, washed with hexane) in .5 ml of tetrahydrofuran was placed in a 10 ml two-neck flask equipped with a reflux condenser, and placed under argon. The diol 14 (.13g, 4.0×10^{-4}mol) in .5 ml of tetrahydrofuran was added to this over 5 minutes at room temperature. Hydrogen gas was released. The solution was colored beige. After 5 minutes of stirring, carbon disulfide (.10ml, 1.7×10^{-3}mol) was added. The color went to dark peachy orange. After 2 hours of stirring at room temperature, methyl iodide (.1ml, 1.6×10^{-3}mol) was added.

The color changed to reddish peach. After ½ hour, ice was added. The product was partitioned between ether and water. The organic layer was dried with magnesium sulfate, and concentrated. The product is a viscous yellow liquid. The yield was .15g (75%). The product was characterized by PMR ($CDCl_3$): 1.27 (triplet, 6H, CH_3's on the esters), 1.80 (broad singlet, 4H, CH_2's not near xanthates), 2.07 (singlet, 2H, CH_2 near xanthate), 2.14 (singlet, 2H, CH_2 near xanthate), 2.53 (singlet, 6H, CH_3's on the xanthates), 4.20 (quartet, 6H, CH_2's on the esters and the bridgehead H's), 6.20 (multiplet, 2H, CH-OXan).

<u>One Method of Pyrolysis of the Dixanthate 18</u>. A sample of the dixanthate was heated under argon at 130° for 4 hours in a round bottom flask. A green liquid formed on the walls. This green liquid was separated off leaving the pure xanthate in the flask. The green liquid was characterized by PMR ($CDCl_3$): 2.73 (singlet). The dixanthate was heated another 2 hours at 190°. Bubbling was noticed and the reaction mixture became darker. The mixture was run through basic alumina with dichloromethane. It appeared to contain some starting material and a new product, which was later identified by comparison with the product of the new method of pyrolysis to be the product of the elimination of one xanthate (although this is not really clear).

Another Method for the Pyrolysis of the Dixanthate 18.

A sample of the dixanthate was placed in a Kugelrohr bulb in a Kugelrohr. The pressure was lowered to .05 torr. The same green liquid impurity as before started coming over. The temperature was raised to 130° for 45 minutes, and more green liquid came over. This fraction was removed. The temperature was raised to 200° for 40 minutes. The fraction that came over was still the green liquid impurity. The reaction bulb contained only the starting material. Then the temperature was raised to 200° for 20 minutes at a pressure of .10 torr. A clear liquid came over . This was identified by PMR to possibly be the product of the elimination of one xanthate. PMR ($CDCl_3$): 1.27 (triplet, approximately 6H, CH_3's on the esters), 1.80 (broad singlet, 4H, CH_2's not near xanthate),1.90-2.20 (multiplet, 2H, CH_2 near xanthate), 2.30 (singlet, approximately 2H, CH_3 on xanthate), 3.60-4.30 (multiplet, 6H, CH_2's on the esters and the bridgehead H's), 5.35-6.20 (broad multiplet, 2H, vinylic protons). This material was then heated in a flask under argon at 200° for 1 hour. The peaks at 2.30 and 2.53 decreased in size in the PMR, and no new vinylic protons showed.

Attempted Preparation of the Dibromide 19. A solution of the spiroditosylate 15 (.50g, 7.9×10^{-4}mol) and lithium bromide (.24g, 2.8×10^{-3}mol) in 10 ml of acetone was placed in a 25 ml flask equipped with a condenser. This was stirred at reflux under argon for 48 hours. White crystals precipitated out, and the solution turned bright orange. The precipitate was filtered off, and water was added to the solution. The product was paritioned between ether and water. The organic layer was dried with magnesium sulfate, and concentrated. The reaction mixture contained some aldol condensation product of acetone, some mono-olefin 13 resulting from the substitution reaction of the Br, and the subsequent elimination of Br_2, and some starting material. There was also an unidentified compound with one peak at 6.85 (broad singlet) in the PMR. The acetone aldol addition product was removed by distillation on a Kugelrohr (pressure was .3 torr, temperature was 25°-55°). The remaining product was run down a dry Florisil column, eluting with a carbon tetrachloride to dichloromethane gradient. The unidentified compound came off in the early fractions with a PMR ($CDCl_3$): 1.20 (singlet, 2H), 1.82 (singlet, 1H), 1.98 (singlet, 1H), 2.11 (singlet, 1H), 2.28 (singlet, 2H), 2.42 (singlet, 1H), 6.85 (broad singlet, 1H).

Preparation of the Diselenide. A solution of diphenyl diselenide (.10g, 3.2×10^{-4}mol, Aldrich) in 2 ml of absolute ethanol was placed in a three-neck flask equipped with a reflux condenser and an addition funnel, which contained the spiroditosylate 15 (.20g, 3.2×10^{-4}mol) in .8 ml of ethanol. The system was placed under argon. While stirring, sodium borohydride (.03g, 7.9×10^{-4}mol) was added in portions over 10 minutes to the solution of the diphenyl diselenide. Bubbling occurred, and the solution changed from yellow to colorless, indicating the formation of the sodium phenyl selenide. Then the spiroditosylate solution was added over 10 minutes. The reaction was stirred for 2 hours at room temperature. Then .05 ml of 10% HCl was added. This was extracted four times with hexane. The hexane extracts were washed with 10% HCl, saturated NaCl solution, and dried with Na_2SO_4. This solution was then put into the refrigerator at 4°, and a solid formed. The solution was decanted off. The solid was yellow. Its PMR gave only peaks in the phenyl region. The mother liquor contained some more of the solid, and an orange liquid which was characterized by PMR ($CDCl_3$): 1.27 (triplet, 10 H, ester CH_3's and CH_2's near Se), 1.82 (broad singlet, 4H, CH_2's not near Se), 2.22-2.42 (multiplet, 2H, CH-Se), 3.90-4.40 (quartet, 6H, CH_2's on

esters and the bridgehead H's), 6.90-7.80 (complex multiplets, integration not calculated due to the presence of the solid with PMR peaks in this region, phenyl H's).

Preparation of the Mono-olefin 13. A solution of the spiroditosylate 15 (9.73g, 1.53×10^{-2}mol), and sodium iodide (28.61g, 1.91×10^{-1}mol, J.T. Baker Chemical Co.) in 100 ml of acetone was placed in a 200 ml flask equipped with a reflux condenser. This was stirred at reflux under argon for 88 hours. The solution was very dark brown (due to I_2 formation) with a white precipitate (Tos-O-Na). Dichloromethane was added. The resulting solution was washed with 10% sodium sulfite solution until the I_2 color was removed. Then the solution was dried with magnesium sulfate, and concentrated. The crude yield was 4.82g (107% due to comtamination with the aldol condensation product of acetone). This was then run through dry Florisil in a column 4 cm in diameter, packed 20 cm high. It was eluted with chloroform. The early fractions contained the product. The yield was 3.70g (82%) of a slighly viscous yellow liquid. The product was characterized by mass spectrometry, PMR, and ^{13}C NMR. The mass spectral molecular weight was 294.1569 (calculated for $C_{15}H_{22}O_4N_2$ was 294.1569).
PMR ($CDCl_3$): 1.23 (triplet, 6H, CH_3's on the esters), 1.77 (broad singlet, 4H, CH_2's), 2.27 (broad singlet, 4H,

allylic CH_2's), 3.97-4.30 (quartet, 6H, CH_2's on the esters and the bridgehead H's), 5.60 (broad singlet, 2H, vinylic H's). ^{13}C NMR ($CDCl_3$): 14.29 (CH_3's of esters), 27.09 (CH_2's), 35.47 (allylic CH_2), 56.98 (allylic CH_2), 61.79 (CH_2's on esters), 66.21 (bridgehead C's), 77.19 (spiro-C), 128.15 (vinylic C), 129.19 (vinylic C), 157.26 ($-CO_2-$).

Preparation of the Allylic Bromide 20 from the Mono-olefin 13. A solution of the mono-olefin 13 (2.56g, 8.71×10^{-3}mol), n-bromosuccinimide (1.53g, 8.59×10^{-3}mol, Aldrich), and .10g of dibenzoyl peroxide (M.C.B.) in 100 ml of carbon tetrachloride was heated at reflux for 2 hours. The end of the reaction was signalled by a precipitate floating at the surface. The mixture was cooled to 0°, filtered, and concentrated. The crude bromide was filtered through Florisil, eluting with ether. This was then concentrated to leave a light brown viscous liquid (2.81g, 87%), which was characterized by PMR ($CDCl_3$): 1.27 (triplet, 6H, CH_3's on esters), 1.87 (broad singlet, 4H, CH_2's), 2.13-2.57 (multiplet, 2H, allylic CH_2), 3.67-4.60 (quartet, 6H, CH_2's on the esters and the bridgehead H's), 5.00 (multiplet, 1H, CHBr), 5.67 (multiplet, 1H, vinylic H), 6.13 (multiplet, 1H, vinylic H).

Elimination of Hydrogen Bromide from the Allylic Bromide 20 to give the Spirodiene 16. A sample of the allylic bromide (2.14g, 5.70×10^{-3}mol) was dissolved in 75 ml of ethyl ether in a 200 ml flask capped with a stopper. The stopper was removed momentarily, and solid potassium tert-butoxide (1.78g, 1.59×10^{-2}mol, MCB) was added all at once. The mixture was stirred for 4 hours at room temperature. Then 5% HCl was added. The solution was extracted with ether,and then CH_2Cl_2. These layers were combined, washed with water, dried with magnesium sulfate, filtered through Florisil, and concentrated. There was a yield of 1.16g (3.97×10^{-3}mol, 69%) of a reddish brown slightly viscous liquid, which was characterized by PMR ($CDCl_3$): 1.30 (triplet, 6H, CH_3's on the esters), 2.07 (singlet, 4H, CH_2's), 3.80-4.50 (quartet, 6H, CH_2's on the esters and the bridgehead H's), 5.96-6.67 (complex pattern characteristic of the conjugated diene in this type of ring system, 4H, vinylic H's).

Preparation of the Diels-Alder Adduct of the Spirodiene 16. A solution of the spirodiene 16 (1.09g, 3.73×10^{-3}mol) and diethyl azodicarboxylate (.73 ml, 4.2×10^{-3}mol, Aldrich) in 50 ml of carbon tetrachloride was heated to 70° for 64 hours. The carbon tetrachloride was removed, and the remaining product was filtered through basic alumina with dichloro-

methane to yield 1.05g (2.25×10^{-3}mol, 60%) of a white solid, compound 21. The product was characterized by PMR ($CDCl_3$): 1.30 (triplet, 12 H, CH_3's on the esters), 1.45-2.10 (multiplet, 4H, CH_2's), 3.80-4.40 (multiplet, 10 H, CH_2's on the esters and the bridgehead H's), 4.73 (broad singlet, 1H, allylic bridgehead), 4.87 (broad singlet, 1H, allylic bridgehead), 6.57 (multiplet, 2H, vinylic H's).

Diimide Reduction of the Diels-Alder Adduct 21. A solution of the adduct 21 (1.05g, 2.25×10^{-3}mol) and hydrazine hydrate (1.09 ml, 2.25×10^{-2}mol, MCB) in 21 ml of ethanol was heated to 61° for 18 hours with O_2 bubbled through the solution. The ethanol was then removed. Ether and water were added. The product was partioned between ether and water. The ether layer was dried with magnesium sulfate, and then concentrated to give 0.926g (1.98×10^{-3}mol, 88%) of a white solid 22. The product was characterized by mass spectrometry, PMR, and ^{13}C NMR. The mass spectral molecular weight was 468.2203 (calculated for $C_{21}H_{32}O_8N_4$ was 468.2220). PMR ($CDCl_3$): 1.27 (triplet, 6H, CH_3's on the esters), 1.30 (triplet, 6H, CH_3's on the esters), 2.90 (broad singlet, 8H, all CH_2's not on esters), 4.00-4.60 (multiplet, 12 H, ester CH_2's and bridgehead H's). ^{13}C NMR ($CDCl_3$): 14.49 (CH_3's), 26.90 (CH_2's not on esters), 27.29 (CH_2's not on

the esters), 60.50 (bridgehead C), 61.15 (bridgehead C), 62.45 (CH_2's on esters), 62.71 (CH_2's on esters), 157.27 (CO_2-).

Preparation of the Bisdiazene 4 from the Adduct 22.

The adduct 22 (473 mg, 1.01 mmol) was dissolved in 110 ml of isopropanol, and put in an addition funnel. The solution had argon bubbled through it for 12 minutes. Potassium hydroxide (1.11g, 24.1 mmol) in 50 ml of isopropanol was added to a three-neck flask equipped with a reflux condenser, addition funnel (containing the solution of 22) and a gas inlet. The system was flushed 15 times with argon using a firestone valve. The KOH/isopropanol was brought to a reflux. The solution of the adduct was added dropwise. The resulting solution was heated at reflux for 3 hours. Then the solution was concentrated to give a brown paste. During this time, as little air as possible was admitted. The paste was taken up in ethanol. A saturated solution of cupric chloride was added until a brown precipitate formed. The precipitate was filtered off through a fine frit filter. The product, a reddish brown solid, was then dissolved in 125 ml of 25% NH_4OH solution to give a bright blue copper ammonia complex. The solution was extracted 6 times with 60 ml of dichloromethane, dried over Na_2SO_4, and concentrated to give

a brown paste. This was sublimed at 110° and .03 torr to give 83.25mg (46.7%) of a white solid, which was then recrystallized from dichloromethane/hexane. The product was identified by comparison to that produced by Lisa McElwee-White according to Scheme III (note: this reaction was also done by Lisa McElwee-White). PMR (C_6D_6): 0.28-1.10 (multiplet, 8H, CH_2's), 3.93 (broad singlet, 2H, bridgehead H's), 4.17 (broad singlet, 2H, bridgehead H's). ^{13}C NMR (CD_2Cl_2): 19.42 (CH_2), 20.33(CH_2), 74.14 (spiro C), 76.09 (bridgehead C), 76.94 (bridgehead C).

Preparation of the PTAD Adduct 24 of the Spirodiene 16. A solution of PTAD (.72g, $4.09x10^{-3}$mol) in enough dichloromethane to dissolve the PTAD was added to the spirodiene 16 (1.16g, $3.97x10^{-3}$mol) while swirling the reaction mixture at room temperature. The red color of the PTAD disappeared on contact with 16. The product solution was filtered through silica gel, eluting with ether. The product was a yellowish solid, compound 24 (1.78g, 96% yield). The product was characterized by PMR ($CDCl_3$): 1.30 (triplet, 3H, ester CH_3), 1.35 (triplet, 3H, ester CH_3), 1.57-2.27 (broad doublet, 4H, CH_2's not on esters), 3.90-4.44 (multiplet, 5H, CH_2's on the esters, and one bridgehead H), 4.44-4.87 (multiplet, 3H, bridgehead H's), 6.54 (broad singlet, 2H, vinylic H's), 7.44 (broad singlet, 5H, phenyl H's).

Diimide Reduction of the PTAD Adduct 24. A solution of the adduct 24 (1.88g, 4.02×10^{-3}mol) and hydrazine hydrate (2.00 ml, 4.13×10^{-2}mol, MCB) in 70 ml of ethanol and 25 ml of dichloromethane was heated to 65° for 28 hours while O_2 was bubbled through the solution. Then the ethanol was removed. Dichloromethane and water were added, and the product was partitioned between them. The organic layer was dried with magnesium sulfate, and concentrated to give 1.66g of a yellow solid 25 (88%). The product was characterized by PMR ($CDCl_3$): 1.25 (triplet, 3H, CH_3 on ester), 1.27 (triplet, 3H, CH_3 on ester), 1.53-2.23 (multiplet, 8H, CH_2's not on the esters), 3.93-4.53 (mutiplet, 8H, CH_2's on esters, and bridgehead H's), 7.13-7.60 (multiplet, 5H, phenyl H's). The product was also characterized by mass spectrometry. The mass spectral molecular weight was 469.1952 (calculated for $C_{23}H_{27}O_6N_5$ was 469.1961).

Preparation of the Bisdiazene 4 from the Adduct 25.
The adduct (457 mg, .97 mmol) was dissolved in 100 ml of isopropanol, and put in an addition funnel. The solution had argon bubbled through it for 12 minutes. Potassium hydroxide (1.07g, 23.2mmol) in 80 ml of isopropanol was added to a three-neck flask equipped with a reflux condenser, addition funnel(containing the solution of the adduct), and a gas inlet. The system was flushed 15 times with argon using a

firestone valve. The KOH/ isopropanol solution was brought to a reflux. The adduct solution was added dropwise. The resulting solution was heated at reflux for 3 hours. Then the solution was concentrated. As little air as possible was allowing in during all transfers. The resulting paste was taken up in ethanol. A saturated solution of $CuCl_2$ was added until a brown precipitate was formed. The precipitate was filtered off using a fine frit filter to give a grayish brown solid. This was then dissolved in 175 ml of a 50% saturated NH_4OH/ 50% water solution to give a bright blue copper ammonia complex. The solution was extracted 5 times with 50 ml of dichloromethane, dried over Na_2SO_4, and concentrated to give a brown solid. This was sublimed at 110° and .07 torr to give 31.37mg (18%) of a yellowish solid. The product was identified by comparison with that produced by other methods.