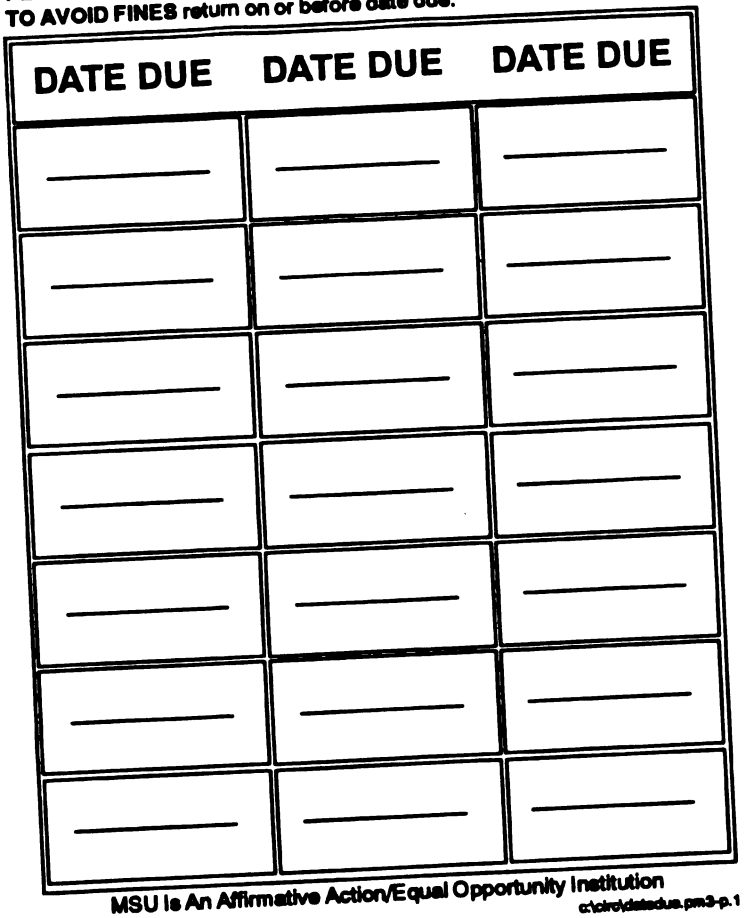

REGIOSELECTIVITY IN THE INTRAMOLECULAR CYCLOADDITION OF DOUBLE BONDS TO TRIPLET BENZENES

By

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A DISSERTATION

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ABSTRACT

REGIOSELECTIVITY IN THE INTRAMOLECULAR CYCLOADDITION OF DOUBLE BONDS TO TRIPLET BENZENES

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The regioselectivity of the intramolecular [2+2] photocycloaddition of *meta*-substituted *para*-butenoxyacetophenones was investigated. Several such ketones were prepared and irradiated using ultraviolet light. Photoreactions were generally followed by ^1H NMR spectroscopy and stable products were isolated using standard chromatography techniques.

Generally, electron-withdrawing *meta*-substituents direct the double bond addition 100% onto the bond between the tether and the electron-withdrawing group. The initially formed tricyclo[6.3.0.0]undeca-2,4-diene derivatives isomerize thermally to their corresponding bicyclo[6.3.0]undec-1,3,5-trienes which on further irradiation cyclize to cyclobutene derivatives. With *meta*-methoxy and thiomethoxy derivatives, the initial bicyclooctatriene photoproducts are favored over the corresponding triene derivatives in an equilibrium mixture. Moreover, the opposite regioselectivity of addition is observed. *Meta*-alkyl substitiuents show strong directing effect for the double bond to add onto the bond between the tether and the substituent. Also, in a competitive study, the double bond prefers to add towards the larger alkyl group.

The reaction is proposed to proceed via exciplex formation between the electron-rich double bond and the electron deficient triplet benzene ring. Strong electron-withdrawing substituents attract the double bond toward them during exciplex formation whereas strong electron-donating groups slightly repel the double bond. With alkyl substituents, which are weak electron-donors, steric effects during both exciplex formation and addition of the triplet benzene to the double bond play dominant roles in the selectivity. Substituents are also found to have strong effects on both secondary photoreactions and thermal rearrangements of the photoproducts.

The photochemistry of *o*-allyloxy-α,α,α-trifluoroacetophenone was also studied. Instead of photocyclization, δ-hydrogen abstraction occurs exclusively to provide vinylbenzofuran derivatives. This behavior, which is similar to that of the corresponding benzophenone but not the acetophenone, is explained in terms of a captodative conjugative effect in the intermediate biradical formed by hydrogen abstraction.

Acknowledgements

My sincere thanks are given to Professor Peter J. Wagner for his guidance and sharing his knowledge through the course of this research. His insight and encouragement are deeply appreciated.

I am also grateful to the National Science Foundation and the National Institute of Health for the research assistantship administrated by Professor Wagner. I would also like to thank the Chemistry Department at Michigan State University for the use of its research facilities.

I also owe special thanks to many friends, specially in Wagner research group. Their friendship and sense of humor made my stay at MSU enjoyable.

Most of all, I thank my wife, Amal, for her love support, encouragement and patience. I am also grateful to my parents, brothers and parents-in-low and brother-in-low for their continuous support.

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INTRODUCTION

One of the most studied functional groups in organic photochemistry is the carbonyl group.[1] Ketones absorb in the easily accessible longer wave length region of the u.v. light and lead in many cases to efficient product formation. In general the carbonyl group is one of the most reactive groups both in the ground and excited states.[2]

On the other hand, aromatic compounds are among the most thermodynamically stable compounds in the ground state. In most of their ground state reactions the aromaticity is preserved. In the excited state, the aromatic ring gains over 70 kcal/mol of excitation energy and becomes different in electronic distribution leading in many cases to nonaromatic products.[1]

Triplet Phenylketones

Phenyl ketones are known to have n,π^* lowest singlets with fast efficient intersystem crossing ($k_{isc} \sim 10^{11}$ sec^{-1}, $\Phi_{isc} = 1$) to their triplet states.[3,4] The lowest triplet may be either n,π^* or π,π^* depending mainly on the ring substituents. The n,π^* transition is a result of excitation of a non-bonding electron to the π^* orbital of the carbonyl group and produces an alkoxy radical-like excited state.[5,6,7] On the other hand, π,π^* triplets shows little radical-like reactivity. This is because of lack of strong spin localization on the carbonyl oxygen.[8]

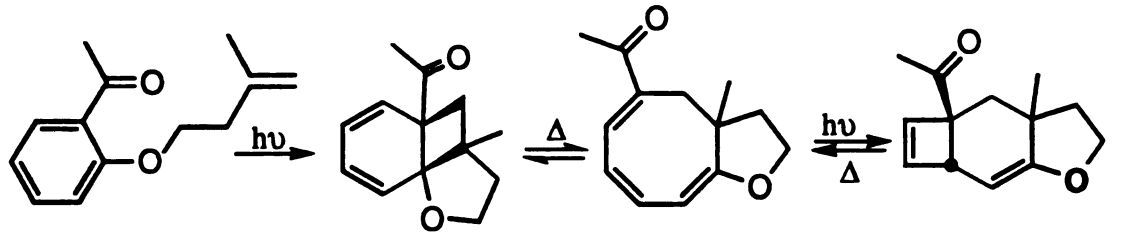
Unsubstituted alkyl phenyl ketones have n,π^* lowest triplets. Their π,π^* triplets are about 2 kcal per mole higher in energy.[9,10,11] In general, electron-donating (+R) substituents at any ring position lower π,π^* and raise n,π^* transition energies so that the π,π^* state is lowest in energy.[11,12,13] Inductively

electron-withdrawing (-I) substituents lower n,π* transition energies relative to π,π* energies.[10,11,12] On the other hand, para conjugatively electron-withdrawing (-R) substituents lower π,π* triplet energies so much more than n,π* energies that the lowest triplet becomes π,π*. Meta (-R) substituents do not stabilize π,π* triplets enough to invert triplet levels.[14]

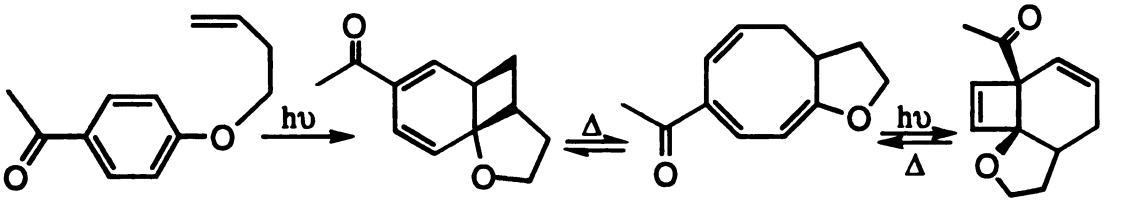
Addition of Triplet Phenylketones to Double Bonds

Photochemical cycloaddition of alkenes to singlet benzenes has been studied for four decades.[15,16] In 1987 Wagner and Nahm[17] discovered a new [2+2] photocycloaddition reaction. They found that double bonds add intramolecularly to phenyl ketones with lowest π,π* triplet states to produce bicyclo[4.2.0]octa-2,4-dienes as initial photoproducts. The reaction proceeds only if the double bond is tethered ortho or para to the keto group (Scheme 1).

The primary photoproduct contains a cyclohexadiene subunit which opens thermally (disrotatory, following the Woodward-Hofman rule) to give all cis cyclooctatriene. This absorbs light and causes one of its two diene units to undergo a disrotatory cyclization to give the final cyclobutene product.[18] The cyclooctatriene was found to be in thermal equilibrium with the initial photoproduct. This equilibrium is strongly affected by ring or side chain substituents.[19,20] In the case of no substituent the equilibrium favors the cyclooctatriene.



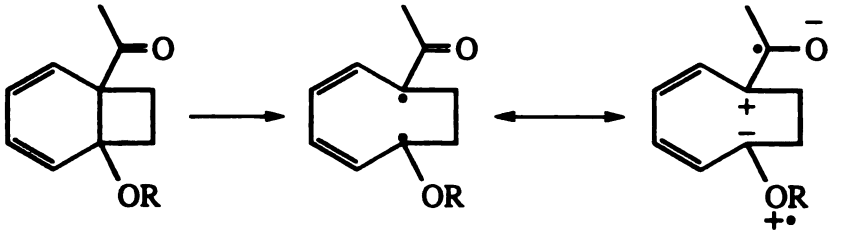
o-Ac-CHD-O_{11} o-Ac-COT-O_{11} o-Ac-LCB-O_{11}



p-Ac-CHD-O_{11} p-Ac-COT-O_{11} p-Ac-ACB-O_{11}

Scheme 1

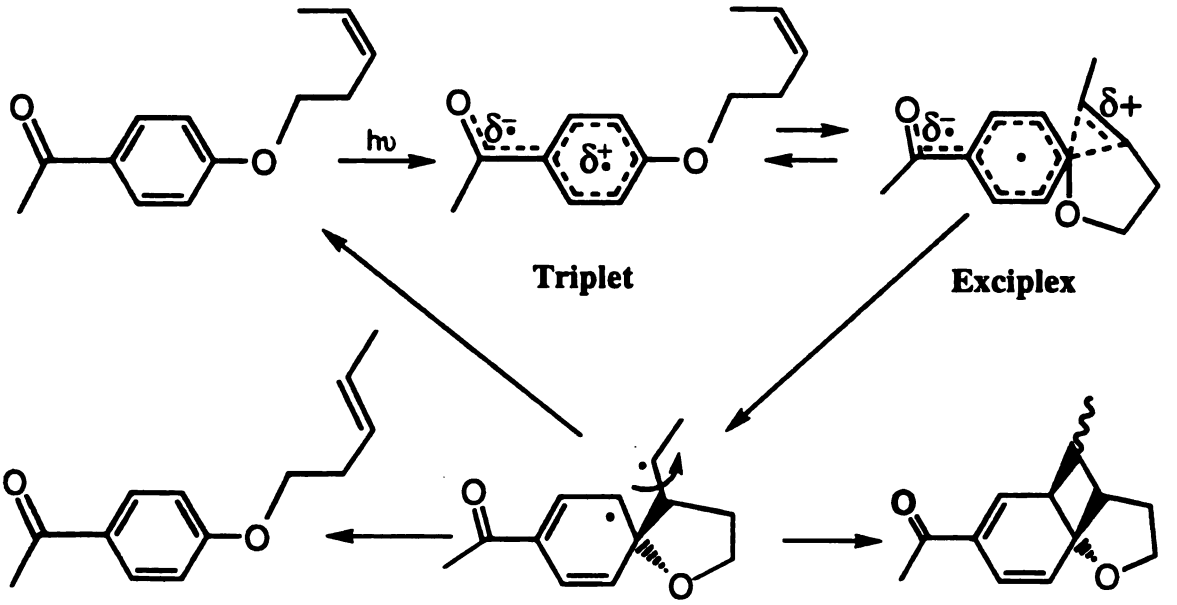
The cyclobutenes were found to be thermally unstable. Upon heating they opened to all cis cyclooctatrienes, a process that does not follow the Woodward-Hoffman rule. It was proposed that the opening probably involves a biradical intermediate and is facilitated by donor-acceptor weakening of the cyclobutane σ bond (Scheme 2).[18]



Scheme 2

Direct irradiation can cause [2+2] cycloaddition of double bonds to substituted benzenes.[21,22] This is true only if there is a strong donor-acceptor interaction between the double bond and the lowest excited singlet state of the substituted benzenes. This means that an activated double bond is needed for the ortho addition to occur from the excited singlet state otherwise meta addition will predominate. For Nahm and Wagner's cycloaddition reaction, unactivated double bonds give only ortho addition products.

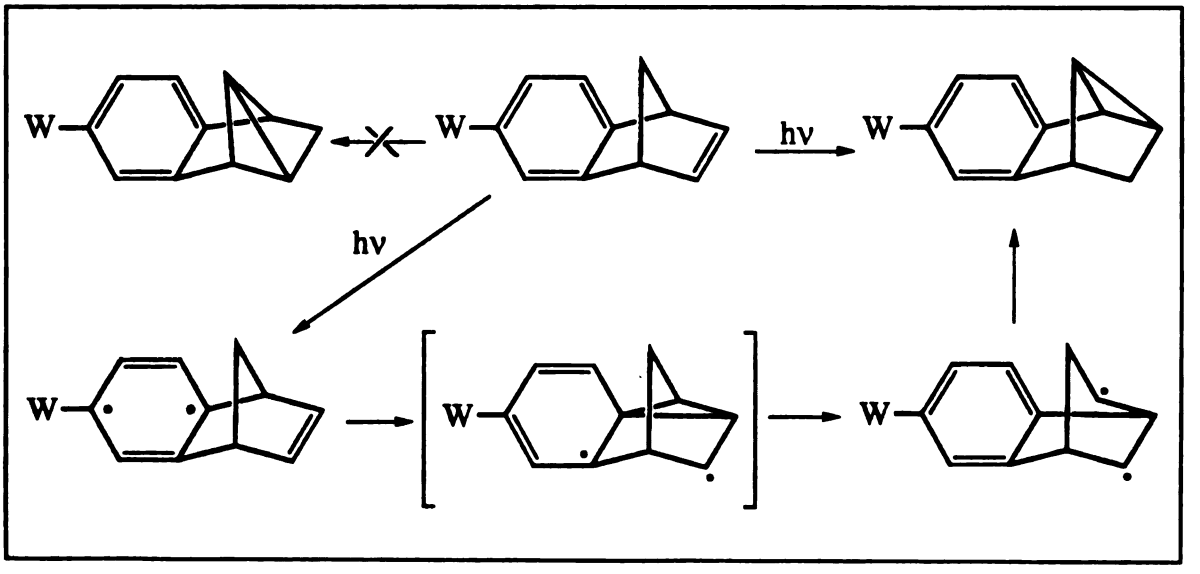
It was proposed that Wagner's cycloaddition reaction occurs from the triplet state since phenyl ketones undergo a very fast intersystem crossing (k ~ 10^{11} s^{-1})[4] with which no other reaction can compete. In addition, product formation was quenched by the addition of triplet quenchers. The π,π^* state was assumed to be responsible for this reaction since *p*-butenoxyacetophenone which has lowest π,π^* triplet state gave the cycloadduct in much higher chemical and quantum yield than *p*-(3-buten-1-oxy) benzophenone which has lowest n,π^* triplet.[17]



Scheme 3

Wagner and Sakamoto[23] studied the triplet decay kinetics for the meta substituted *p*-alkenoxyacetophenones over a wide temperature range. They found that activation energies varied from 5.0 kcal/mol for a *m*-methoxy to 3.0 kcal/mol for m-cyano whereas it was 4.3 kcal/mol for the *m*-methyl and 3.9 kcal/mol for the unsubstituted *p*-alkenoxyacetophenone. That electron-withdrawing groups (CN) increase triplet reactivity whereas electron-donating groups (OMe) suppress reactivity supports the originally proposed idea that the electron rich double bond acts as an electron donor to the electron deficient triplet benzene ring forming an exciplex.

Generally, it is hard to know what is the exact electronic charge and spin density distribution of excited states. However, it can be predicted from reaction products, kinetics, some spectroscopic analysis, and quantum mechanical calculations. Paquette and co-workers[24] reported several examples of regiospecificity in the di-π–methane rearrangements of benzonorbornadienes substituted by electron donating or electron withdrawing groups. They have



Scheme 4

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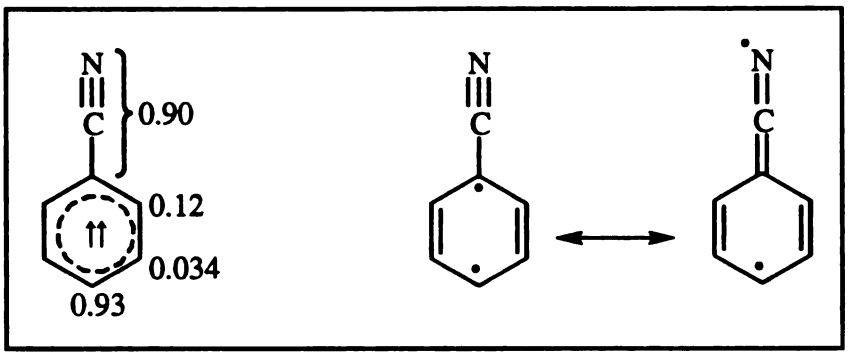
shown that cyano and acetyl substituents direct the rearrangement such that the double bond bridges to the benzene ring ortho or para but not meta (Scheme 4). This is in agreement with Wagner's[25] and Hirota's[26] findings that spin density in triplet benzonitriles is highest ortho and para to the nitrile group (Scheme 5). This situation can be extended to the π,π^* triplets of acetophenones.



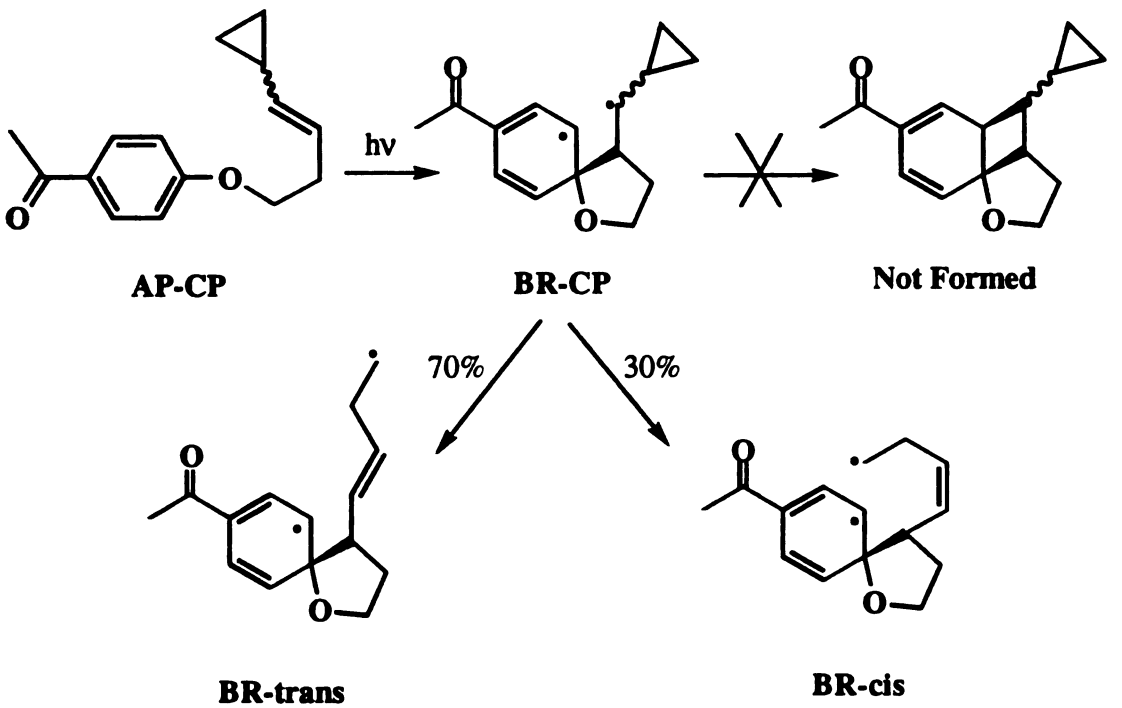
Scheme 5

Wagner also pointed out that the benzonitrile triplet is essentially a 1,4 diradical.[25] This was proved by analyzing the EPR spectra of triplet fluoro-benzonitriles. Results showed that spin density on the carbon para to the cyano group is close to unity and the bond between C_1 and C_2 (C_6) to be nearly a single bond, whereas those between C_2, C_3 and C_5, C_6 are nearly double bonds. This strongly suggested that the most dominant valance bond structure for the benzonitrile triplet state has a quinoidal structure. It was also proposed that the π,π^* triplets have charge transfer character with the ring being electron deficient and the carbonyl electron rich.[12]

After exciplex formation, the radical center para to the acetyl group adds to the double bond to give a 1,4 biradical which will either close to the initial photoproduct or cleave to give starting material (a mixture of cis and trans

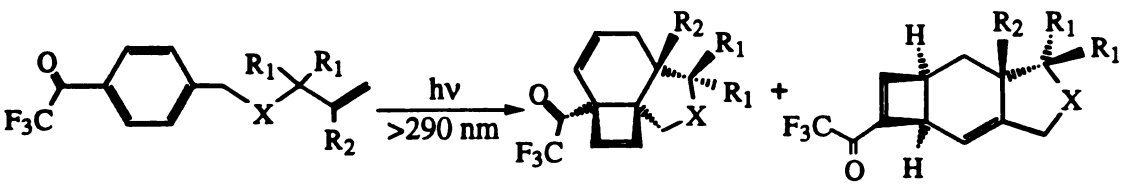
olefins). Observation of cis→trans isomerization supports the idea of a biradical intermediate.[17]

The intermediacy of a 1,4 biradical was supported by studying the photochemistry of **AP-CP** which has a cyclopropyl group at the double bond.[27] Analysis showed that none of the products has the cyclopropyl ring intact. The opening of the cyclopropyl ring verifies the existence of a biradical intermediate (Scheme 6).[27]



Scheme 6

Wagner and Alehashem[28] studied several compounds in which the unsaturated tether is anchored to the benzene ring with a methylene group. They found that irradiation of the compounds below produced a mixture of two isomeric cyclobutenes (Scheme 7).

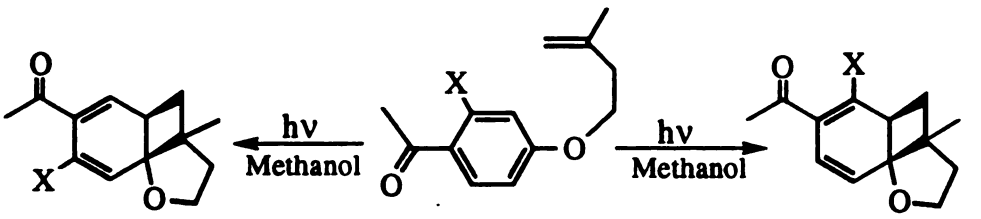


R_1=R_2=H; X=O
R_1=H; R_2=Me; X=O
R_2=H; R_1=Me; X=O
R_1=R_2=H; X=CH_2

p-TFA-ACB-$X_{10}C_{11}$ **p-TFA-LCB-$X_{10}C_{11}$**

Scheme 7

Wagner and Smart have demonstrated in another system that this reaction can show a high degree of regioselectivety[19]. Substituents ortho to the acetyl group were found to direct the double bond towards them. Fluorine was found to give 9% of the other isomer (Scheme 8).

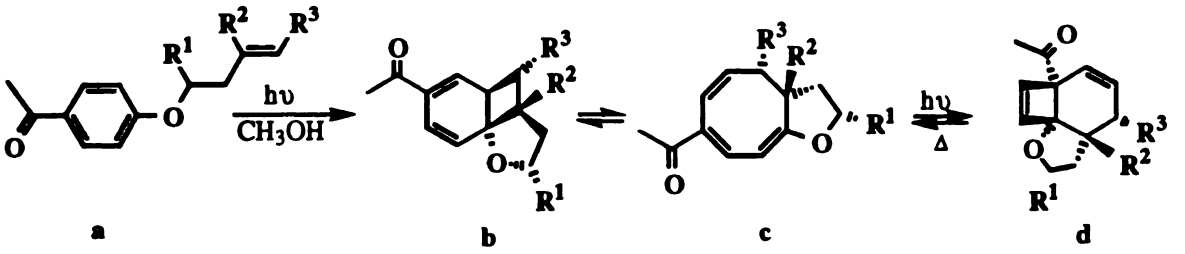


X= F (9%)

X= CF_3, Me, OMe and F (91%)

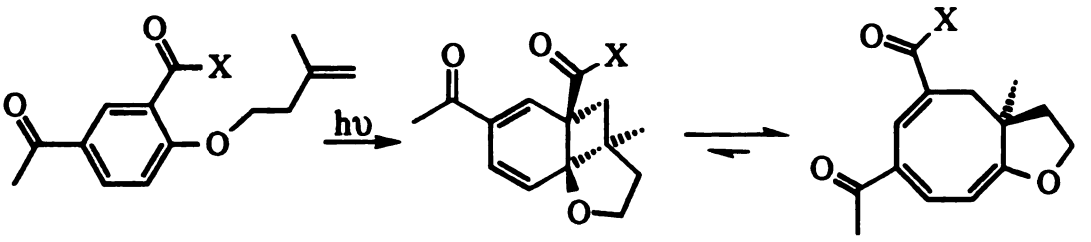
Scheme 8

Wagner and Cheng[20] studied the diastereoselectivity observed when *o*- and *p*-butenoxyacetophenones undergo [2+2] photocycloadditions. They always found R^2 syn to the cyclobutene ring in compounds of type **d.** Also, in every case R^1 and R^3 are trans to each other in the major products (Scheme 9).



Scheme 9

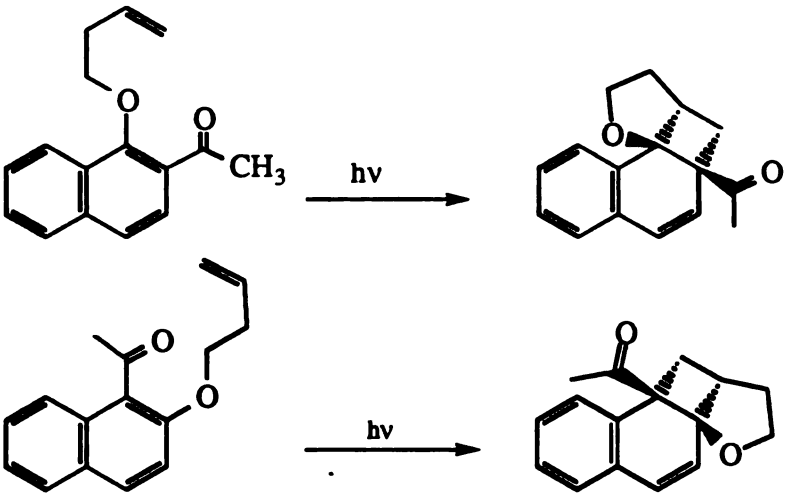
Later, Wagner and McMahon[29] reported that high diastereoselectivity can be achieved in the cycloaddition reaction through the use of chiral auxiliaries. They showed that by introducing a chiral amide group ortho to the tether, 90% diastereoselectivity was obtained (Scheme 10).



Auxilairy (X)	% de
OH	0
(2R,5R)-(-)-2,5-dimethylpyrrolidine	90
(7R)-(+)-camphorsultam	90

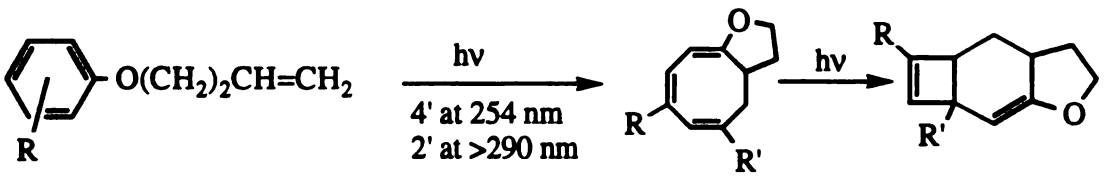
Scheme 10

In another system Wagner and Sakamoto[30] found that irradiation of both 1-butenoxy-2-acetonaphthone and 2-butenoxy-1-acetonaphthone promoted [2+2] cycloaddition from their triplet states. Sakamoto also looked at a few meta substituents and found evidence for high regioselectivity (Scheme 11).



Scheme 11

Gilbert and coworkers[31] found that 2'- and 4'- cyano substituted 4-phenoxybut-1-ene undergo intramolecular ortho cycloaddition upon irradiation at $\lambda = 254$ nm and $\lambda \geq 290$ nm respectively. The formation of the cyclooctatriene was quenched by 1,3 dienes whereas its intramolecular cyclization to cyclobutene was not quenched (Scheme 12).



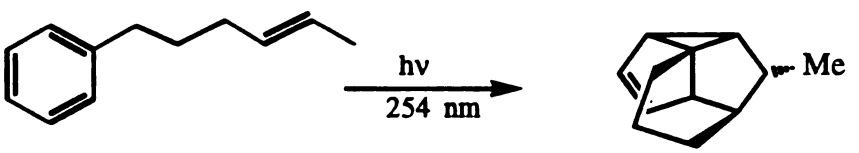
R=2' CN
4' CN

R=CN, R'= H
R=H R'= CN

Scheme 12

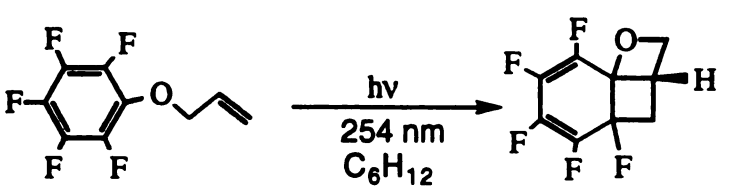
Photocycloaddition of Double Bonds to Benzenes

The photochemistry of benzenes has been known for over forty years. Following the discovery of the formation of fulvene after irradiation of benzene, the intermolecular ortho photocycloaddition of olefins to benzene was discovered[32]. In two independent studies in 1966 Wilzbach and Kaplan[33] and Bryce-Smith, Gilbert and Orger[34] discovered the 1,3-(meta) photocycloaddition



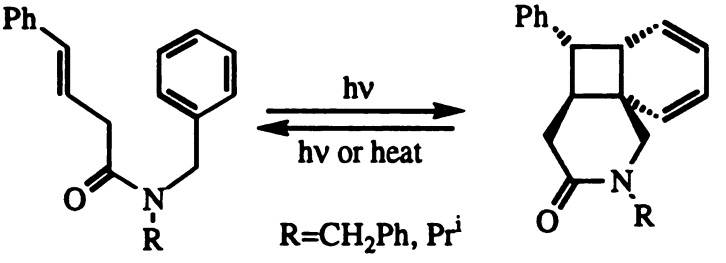
of simple alkenes to benzene. In 1971 Morrison and coworkers[35] studied the intramolecular version of this reaction. Since then this area has been dramatically developed leading to the application of this reaction in the synthesis of polycyclic compounds.[15]

Since the discovery of arene-alkene photocycloaddition, many research groups have studied this reaction either mechanistically or synthetically. Zupan and coworkers[36] found that irradiation of pentafluorophenyl-prop-2-enyl ether at 254 nm resulted in intramolecular [2+2] cycloaddition, forming 2,3,4,5,6-pentafluoro-1,8-epoximethano bicyclo[4.2.0]octa-2,4-diene (Scheme 13).



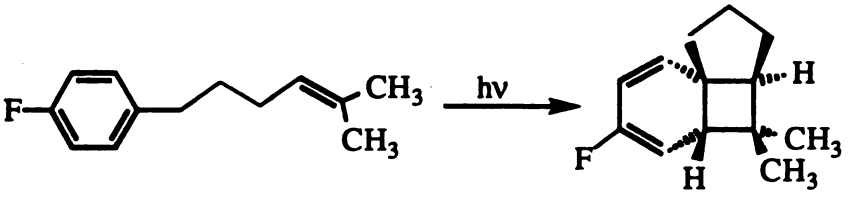
Scheme 13

Aoyama and coworkers[37] demonstrated the first example of [2+2] cycloaddition of styrenes to benzenes. They irradiated *N*-benzylstyryl-acetamide in methanol using a low pressure mercury lamp and obtained a tricyclic product which reverts to starting material upon heating or photolysis (Scheme 14).



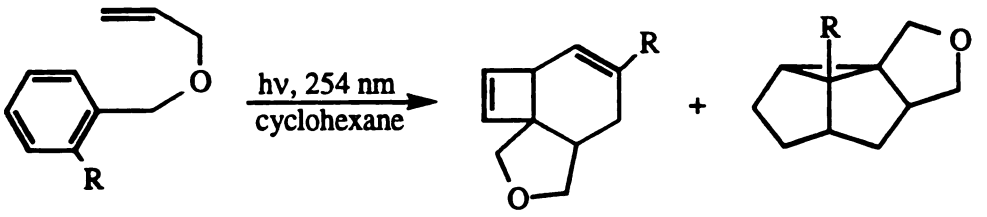
Scheme 14

Cornelisse and coworkers[38] found that irradiation of 2-methyl-6-(fluorophenyl)hex-2-ene produced a [2+2] photocycloaddition product. The terminal methyl groups are essential for the reaction to occur otherwise meta cycloaddition products predominate (Scheme 15).



Scheme 15

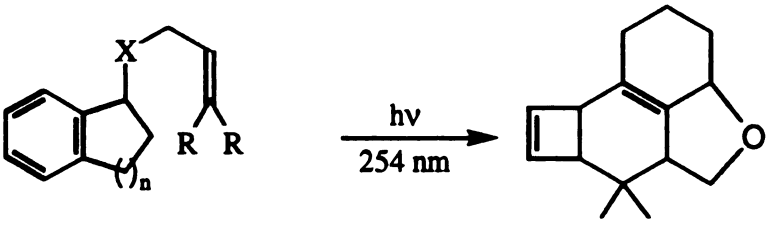
o-Methyl and methoxy substituted 3-benzyloxyprop-2-enes were found to undergo ortho [2+2] photocycloaddition as a minor pathway.[39] The major reaction was the meta photocycloaddition reaction to produce linear triquinane derivatives (Scheme 16).



R=Me	1	:	12
R=OMe	1	:	2.5

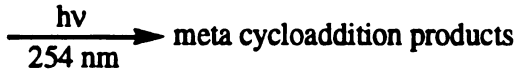
Scheme 16

Gilbert and coworkers[39] found that when 1-(1',2',3',4'-tetra-hydro-1'-naphthyloxy)-3-methylbut-2-ene was irradiated at 254 nm, the major photoproduct was a result of initial intramolecular 1,2 cycloaddition. The other reactants shown below gave meta cycloaddition products only (Scheme 17).



X=O, n=2, R=Me

X=CH_2, n=2, R=H
X=O, n=2, R=H
X=O, n=1, R=H
X=O, n=1, R=Me



Scheme 17

On the other hand, Keese and coworkers[40] found that irradiation of the substituted 7-methoxyindanes shown below led to photoproducts which arise from an ortho [2+2] cycloaddition reaction along with other meta cycloaddition products (Scheme 18).

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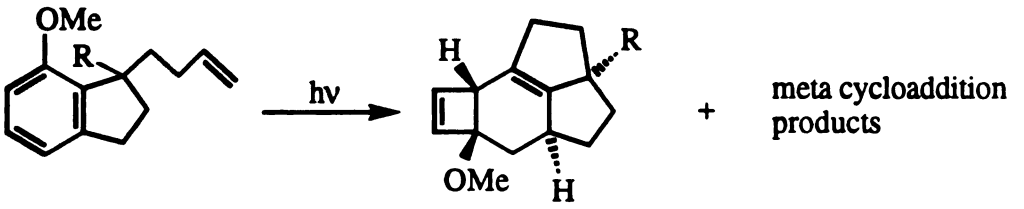
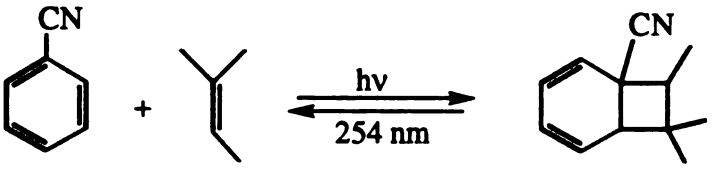


R=OH	1	:	1
R=H	3.5	:	2.5

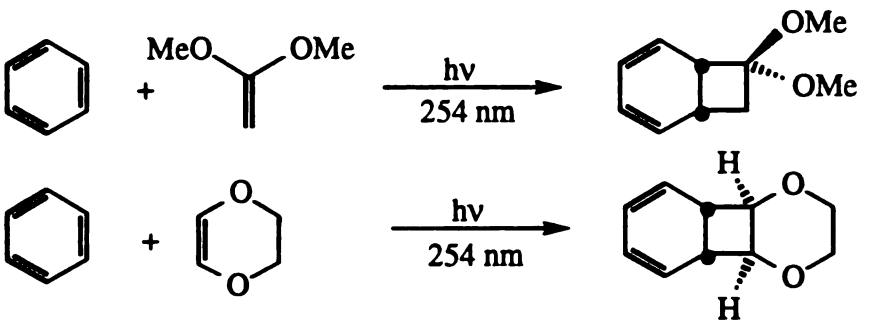
Scheme 18

The first example of intermolecular photocycloaddition reaction of simple alkene to benzenes was reported in 1963.[41] 2-Methyl-2-butene was found to add to benzonitrile when irradiated at 254 nm. The ortho cycloaddition product formed was found to be photoreactive and reverted to starting materials upon further irradiation (Scheme 19).



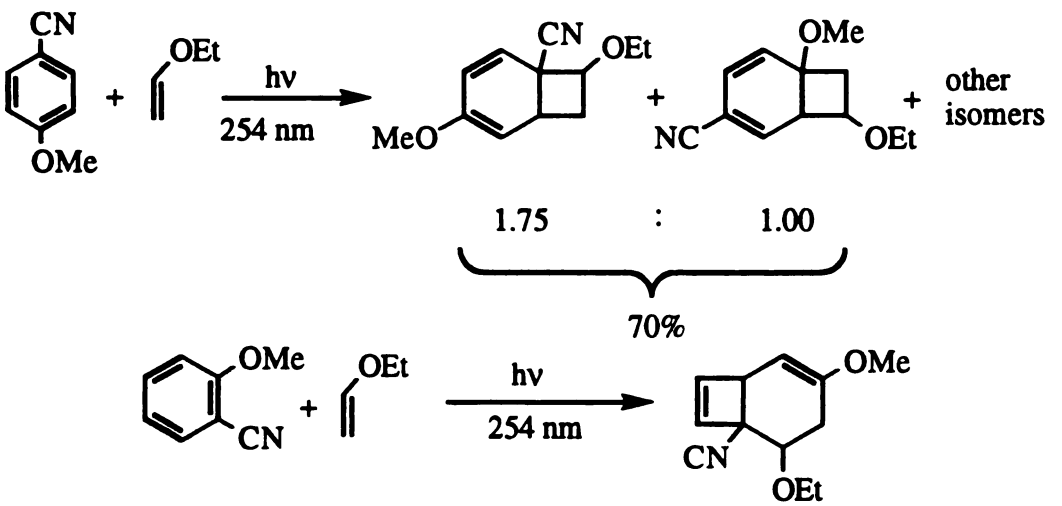
Scheme 19

Gilbert and coworkers[42] found that 1,1-dimethoxyethylene and 2,3-dihydro-1,4-dioxin add to benzene when irradiated at 254 nm affording the ortho cycloaddition products (Scheme 20).



Scheme 20

It was also found that ethyl vinyl ether adds photochemically to both ortho and para cyanoanisole to give ortho cycloaddition products.[43] The reaction was regioselective for the ortho isomer whereas the para isomer gave two different regioisomers as the major products (Scheme 21).



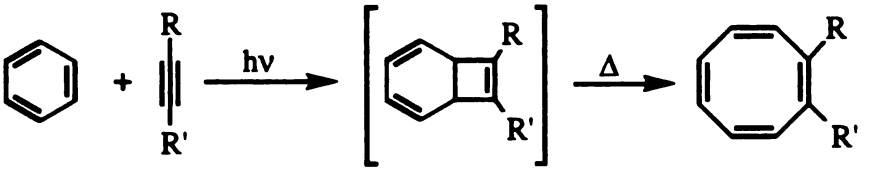
Scheme 21

It should be mentioned that the ortho photocycloaddition of naphthalenes is also known. The reaction proceed via kinetically well defined singlet exciplexes.[44] Wagner and Sakamoto[30] reported the only example for the 1,2

photocycloaddition of double bonds to triplet naphthalenes whereas Dopp and coworkers reported the 1,4 triplet cycloaddition reaction.[45]

Addition of Triple Bonds to Arenes

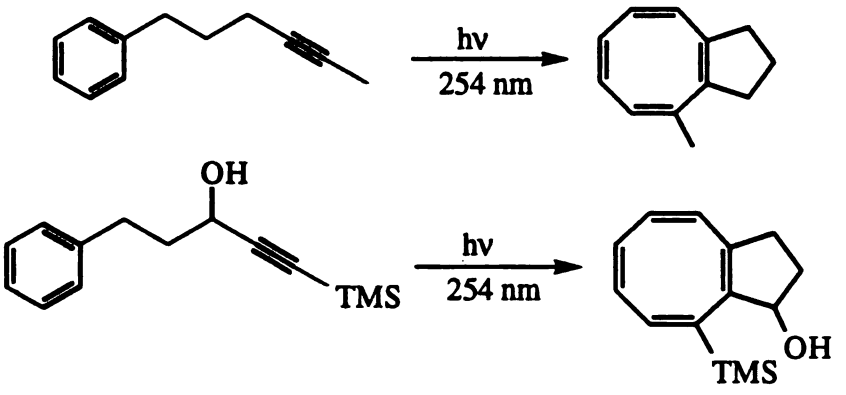
Alkynes were found also to undergo the ortho photocycloaddition reaction[46]. The initial cycloadducts usually rearrange directly to cyclooctatetraene products (Scheme 22).



R=R'= H
R=R'=COOMe
R=COOMe, R'=t=Bu

Scheme 22

The intramolecular version of this reaction is also known. Morrison and coworkers[47] irradiated 6-phenyl-2-hexyne at 254 nm and observed the formation

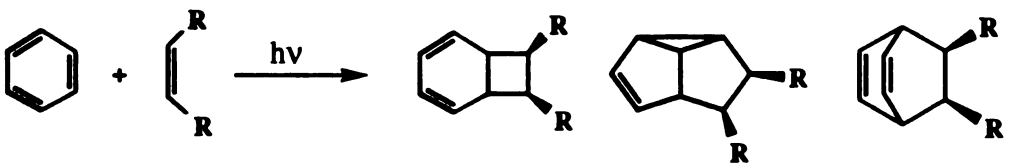


Scheme 23

of cyclooctatetraene in very low quantum and chemical yields. Pirrung[48] found that placement of trimethylsilyl group on the alkyne improved the reaction efficiency (Scheme 23).

Selectivity in Photocycloaddition of Singlet Benzenes to Olefins

Double bonds can add to the excited singlet arene to give ortho- and/or meta- adduct(s)[15] (Scheme 24). The para addition process is limited to only a few cases. The mode of the addition depends on the olefin as well as the substituents on the benzene ring.



Scheme 24

Bryce-Smith[49] reported that the ortho addition predominates if charge transfer between the arene and the double bond is involved or if the ionization potential difference between the arene and olefin is greater than 0.4 eV. On the other hand, the meta photocycloaddition predominates if the ionization potential difference is less than 0.4 eV.

Morrison and Ferree[50] suggested that the reaction proceeds via an exciplex between the excited benzene ring and the double bond. Later Leismann and Mattay[51] observed exciplex emission during the photocycloaddition of benzene to various olefins.

In a qualitative theoretical study based on orbital symmetry and frontier molecular orbital analysis, Houk[52] has provided explanation for the partitioning

of cyclooctatetraene in very low quantum and chemical yields. Pirrung[48] found that placement of trimethylsilyl group on the alkyne improved the reaction efficiency (Scheme 23).

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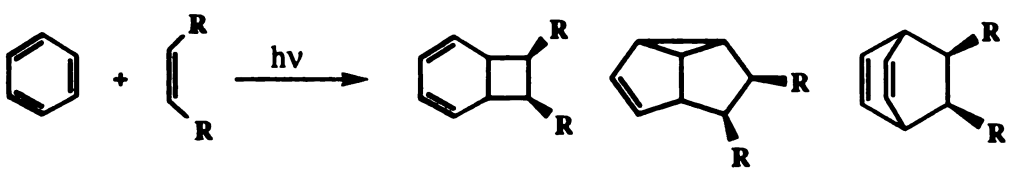

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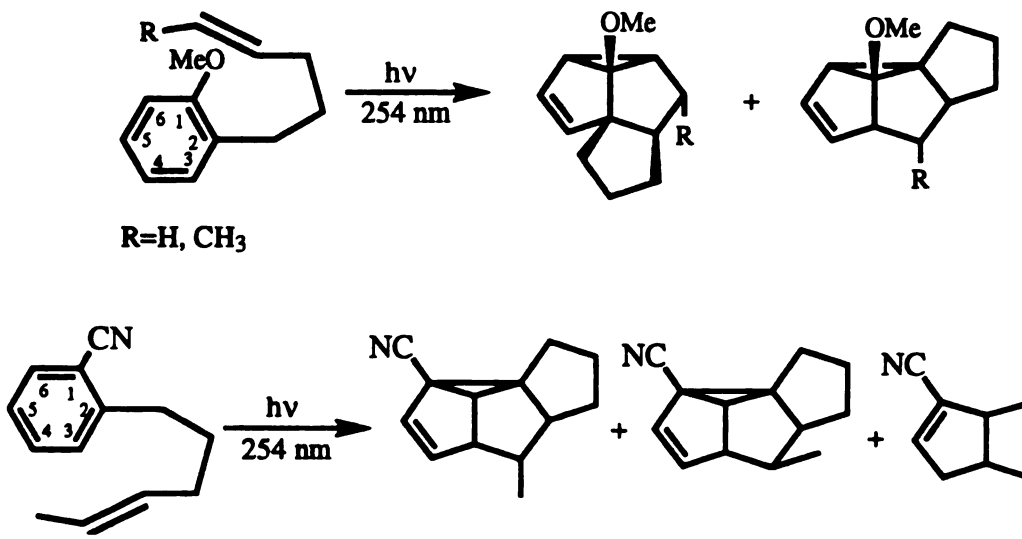
In a qualitative theoretical study based on orbital symmetry and frontier molecular orbital analysis, Houk[52] has provided explanation for the partitioning

between ortho-, meta-, and para cycloadditions. The benzene lowest excited singlet $^1B_{2u}$ can be represented as a combination between S→A* and A→S*. The ortho addition could be achieved by the interaction of the benzene A orbital with the ethylene HOMO or the benzene A* orbital with the ethylene LUMO. The meta addition is due to interaction between the benzene S with the ethylene HOMO or the benzene A* with the ethylene LUMO. The para addition is due to the weak interaction of the ethylene HOMO with the benzene S*. This means that the S→A* transition will stabilize the meta complex more than the ortho, while the A→S* transition will stabilize the ortho only.

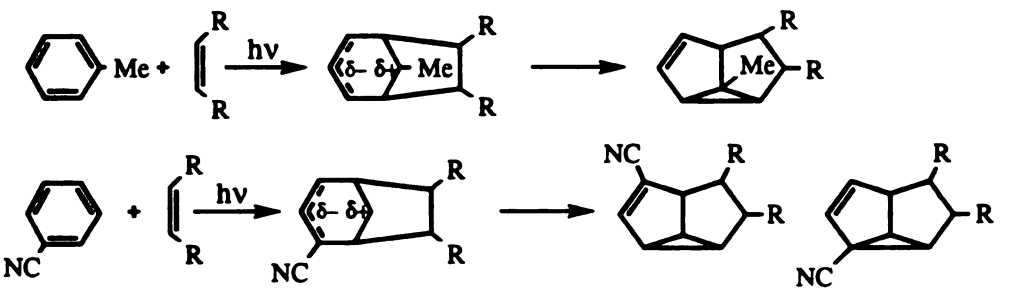
One well-known generalization about the reaction is that electron-donating substituents on the benzene ring direct the olefin to add to the C_2 and C_6 positions, whereas electron withdrawing groups direct the double bond to add to the C_2 and C_4 positions (Scheme 25).



Scheme 25

The high selectivity was explained by proposing the formation of a dipolar intermediate following the exciplex formation.[21b] This rationalization was

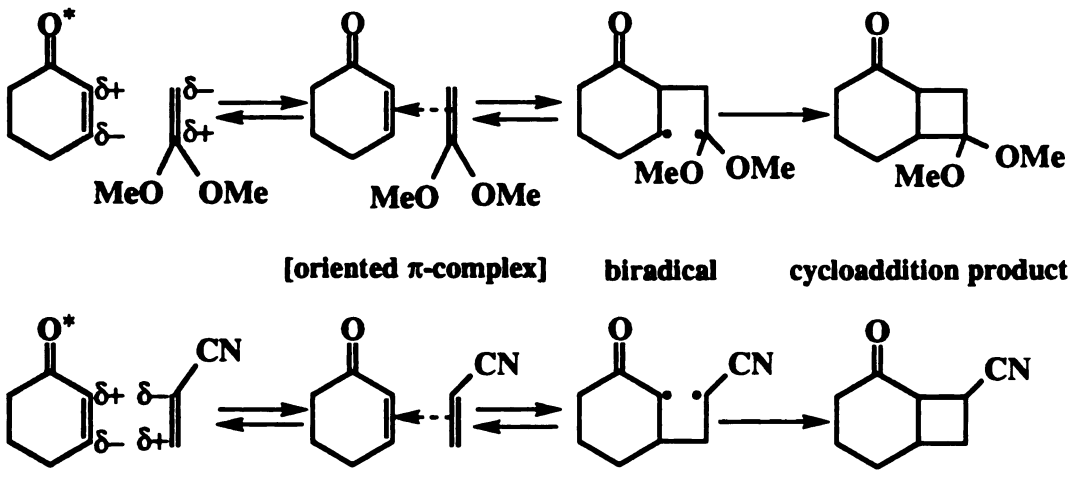
supported by semi-empirical calculations which shows that on the approach of the olefin, the ring becomes polarized.[53](Scheme 26)



Scheme 26

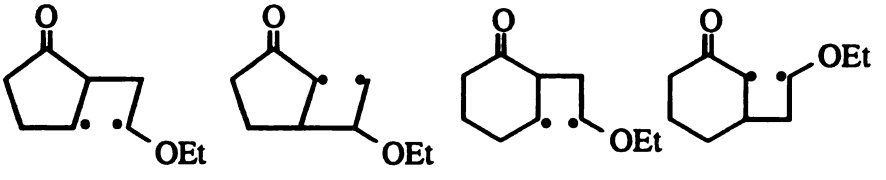
[2+2] Photocycloaddition to Enones and Dienones

One of the most widely used photochemical reactions in organic synthesis is the [2+2] photocycloaddition of enones to alkenes. Since the reaction's discovery[54] in 1962, many research groups have explored its mechanism, which has been the subject of some controversy.[55] Based on the regiochemistry of the addition of enones to polar olefins, Corey, suggested that the enone excited state, which has a polarity opposite to its ground state, would form an oriented π–complex with the ground state of the olefin (Scheme 27).[56] The excited state was proposed to be an n,π^* triplet that adds to the olefin to form a biradical which couples to products.



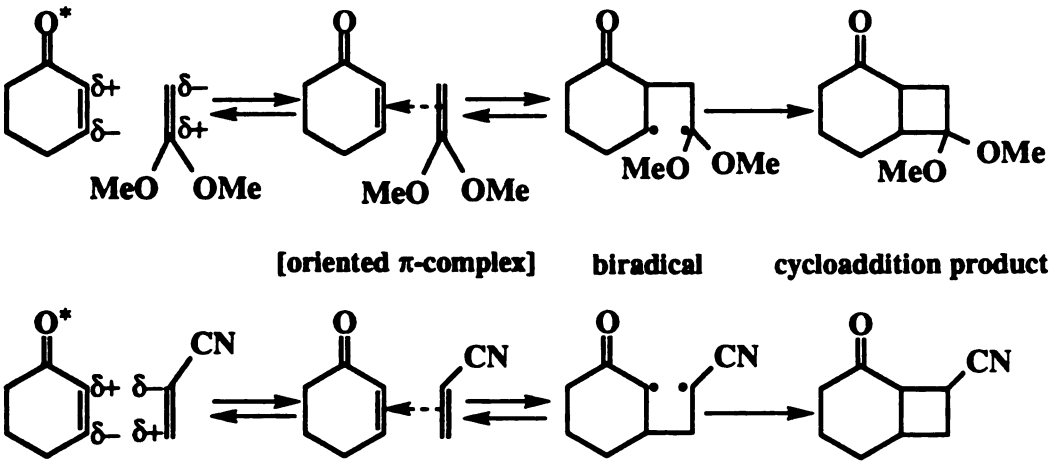
Scheme 27

Recent studies showed that there is no evidence to support Corey's hypothesis of the oriented π–complex formation. Also the excited state responsible for the reaction was found to be the π,π* triplet not the n,π* triplet. Weedon and his group performed several experiments in which biradicals from the reaction of cyclopentenone[57,58] or cyolohexenone[59] with olefins were trapped using H_2Se. The results showed that biradicals arising from both "favored and unfavored orientations" are formed in nearly 1 : 1 ratio (Scheme 28). In other experiments he generated the biradicals independently and found that they undergo reversion to starting materials to different extents.



biradical ratio	1	:	1	1.2	:	1
product ratio	3.1	:	1	4.3	:	1

Scheme 28



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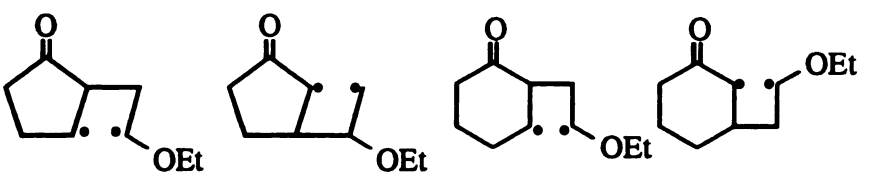
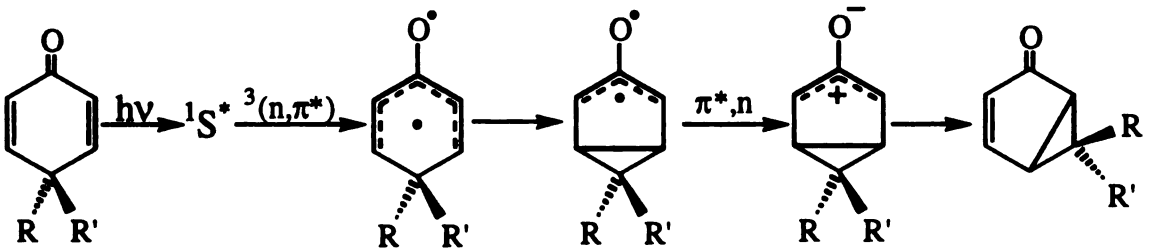


biradical ratio	1	:	1	1.2	:	1
product ratio	3.1	:	1	4.3	:	1

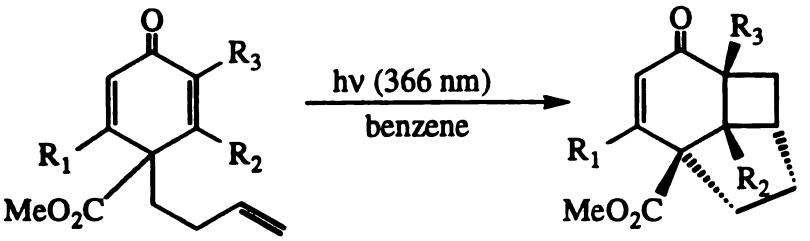
Scheme 28

Cross-conjugated cyclohexadienones are known to rearrange photochemically and form bicyclo[3.1.0]hex-3-en-2-ones[60] (type A photo-rearrangement) (Scheme 29). The rearrangement was proposed to occur from the n,π* triplet followed by bonding between C_3 and C_4 to give a bicyclic molecule which is still electronically excited. This step is followed by π* to n electron demotion, affording the ground state of zwitterion which rearranges to the final product.[61,62]



Scheme 29

Schultz discovered that cross-conjugated cyclohexenone can undergo both inter-[63] and intra-molecular[64] photocycloaddition to double bonds. The addition of the double bond was found to be greatly regoiselective. When a methoxy group was placed on C_2 of the dienone, the olefin added to the substituted double bond whereas the addition favored the unsubstituted double bond if the methoxy group was at C_3. On the other hand the addition was mainly towards the methyl group for the C_3-methoxy and C_5-methyl substituted dienone (Scheme 30). The author proposed that the reaction occurs from the π,π* triplet state. The reaction was proposed to have a biradical intermediate, since using a cis or trans substituted olefin led to isomerization of the double bond in the recovered starting material.

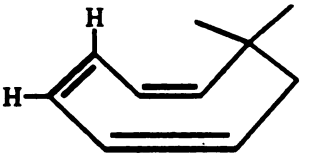


R_1=OMe;R_2=R_3=H	R_1=OMe;R_2=R_3=H	95%
	R_1=R_3=H;R_2=OMe	5%
R_1=OMe;R_2=Me;R_3=H	R_1=OMe;R_2=Me;R_3=H	87%
	R_1=Me;R_2=OMe;R_3=H	13%
R_1=R_2=H;R_3=OMe	R_1=R_2=H;R_3=OMe	

Scheme 30

Thermal and Photochemical Transformation of Photoproducts

Cope[65] was the first to observe that cycloocta-1,3,5-triene exits in equilibrium with bicyclo[4.2.0]octa-2,4-diene. Later, it was found that substituents greatly affect the equilibrium constant between the two isomers. Substituents in the 7,8 positions of the cyclooctatriene system were found to shift the equilibrium towards the bicyclic compound. The significant increase of K_{eq} for the trans- 7,8 disubstituted olefin compared to the cis isomer is due to steric effect of an endo group in the concavity of the cyclooctatriene tub[66].



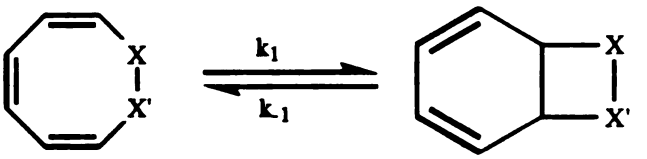
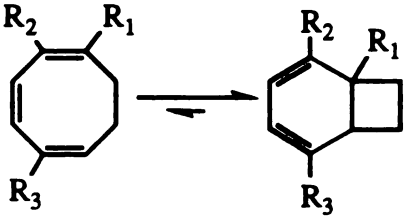


Table 1: Rate and equilibrium constants for 7- and 8- substituted cyclooctatrienes and their corresponding cyclohexadienes.

X X'	Keq at 60°C	k1 (sec^{-1}) at 20°C	Ref.	X X'	Keq at 60°C	k1 (sec^{-1}) at 20°C	Ref.
CH_2 CH_2	0.12	5.3×10^{-7}	66	H, OAc H, OAc	> 19		66
H, CH_3 CH_3, H	4.26		66	OCH_3 OCH_3 CH_2	> 19		66
H, CH_3 H, CH_3	15.67		66	H, OAc CH_2	1.13	8.1×10^{-6}	66
H, Cl Cl, H	4	3.3×10^{-6}	66	H, Br CH_2	0.54	6.0×10^{-6}	66
H, Cl H, Cl	99 (-30°C)	1.0×10^{-3}	66	H O H	0.04	1.9×10^{-7}	66
	2.33 (RT)	1.1×10^{-5}	67		0.43 (RT)		67

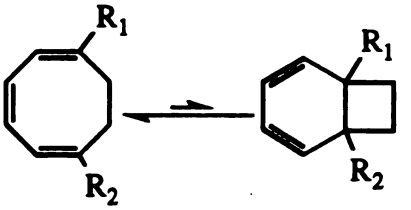
Oda[68] found that 2,5-diphenylbicyclo[4.2.0]octa-2,4-diene exists in the bicyclic form at room temperature to 100°C. This is due to the tendency of the phenyl groups to conjugate with the almost planar cyclohexadiene moiety. Streitwieser[69] also found that 1,5-di-*tert*-butyl-1,3,5-cyclooctatriene exists exclusively in the bicyclic form, and attributed this to a relaxation of steric compression (Scheme 31).



R_1=H;R_2=R_3=Ph
R_1=R_3=*t*-Bu;R_2=H

Scheme 31

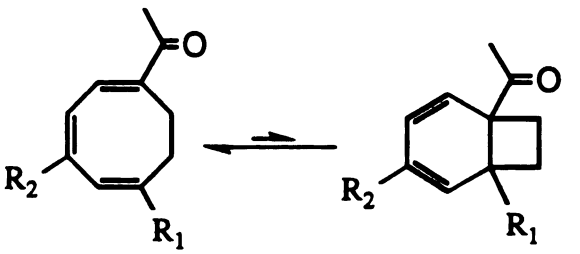
On the other hand, Vogel[70] found that conjugatively electron-withdrawing substituents in the 1- or 1- and 6- position of the bicyclic compound rearranges very easily to the eight-membered isomer. This is due to the substituent conjugation with the triene system and to the unfavorable conformation of the two neighboring cis-substituents in the four-membered ring (Scheme 32).



R_1=H; R_2=COOMe
R_1=R_2= COOH
R_1=R_2= COOMe

Scheme 32

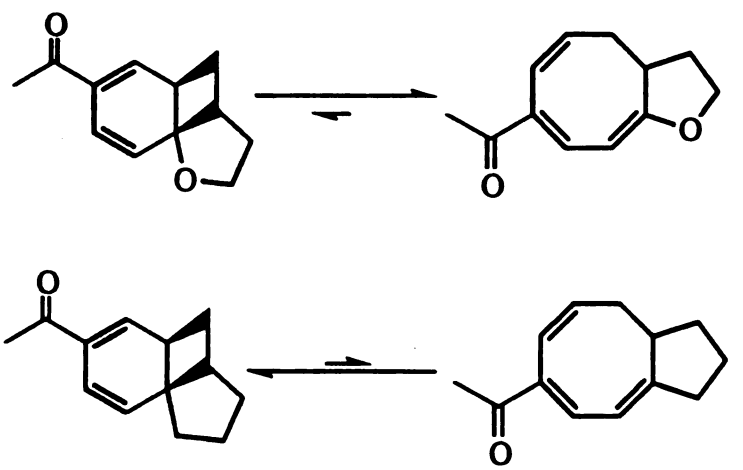
The previous results were confirmed by Takeda and coworkers[71] who found that the stabilization provided by conjugation with a single carbonyl group is great enough to maintain the triene structure (Scheme 33).



$R_1 = R_2 = H$
R_1=Me, R_2= H
R_1=H, R_2= Me
$R_1 = R_2$= Me

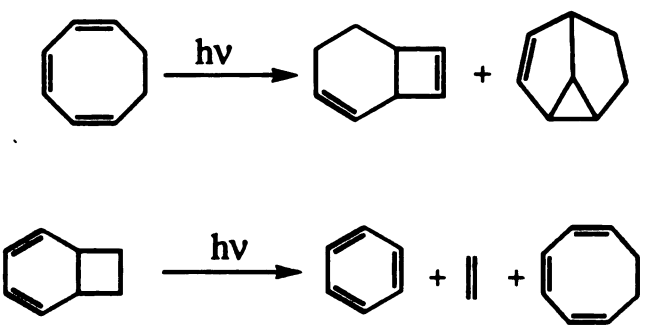
Scheme 33

Wagner and coworkers[18,28] also found that 4-acetyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene exists in the triene form whereas replacing the ether oxygen with a methylene group reversed the equilibrium to favor the corresponding diene component (Scheme 34).



Scheme 34

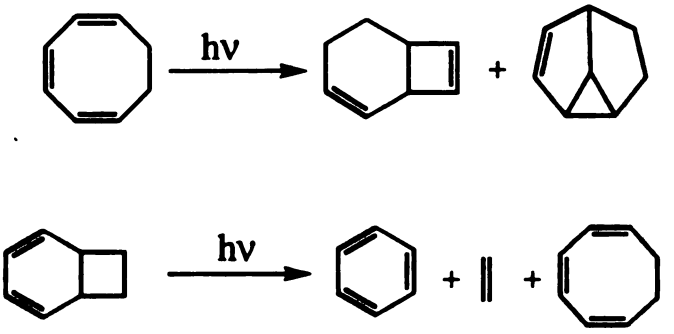
Irradiation of 1,3,5-cyclooctatriene in ether[72], pentane[73] or in the gas phase[74] led to the formation of a mixture of bicyclo[4.2.0]octa-2,7-diene and tricyclo[3.2.1.$0^{2,8}$]-3-octene. On the other hand irradiation of bicyclo[4.2.0]- oct-2,4-diene led to the formation of a mixture of benzene, ethylene, and 1,3,5-cyclooctatriene (Scheme 35).



Scheme 35

Direct irradiation of cyano-benzocyclooctatrienes gave a mixture of two possible cyano-2,3-benzobicyclo[4.2.0]octa-2,4,7-trienes arising from electrocyclization of the two diene subunits of the reactant.[75] The regioselectivity of cyclization depended greatly on the position of the cyano group. It was also found[76] that direct irradiation of 6,7-dimethyl-benzocyclooctatrienes gave only one regioisomer (Scheme 36).

Irradiation of 1,3,5-cyclooctatriene in ether[72], pentane[73] or in the gas phase[74] led to the formation of a mixture of bicyclo[4.2.0]octa-2,7-diene and tricyclo[3.2.1.$0^{2,8}$]-3-octene. On the other hand irradiation of bicyclo[4.2.0]- oct-2,4-diene led to the formation of a mixture of benzene, ethylene, and 1,3,5-cyclooctatriene (Scheme 35).



Scheme 35

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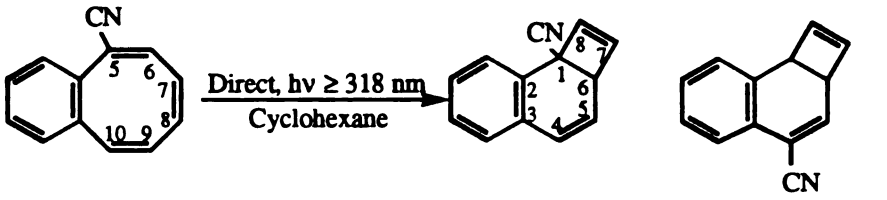
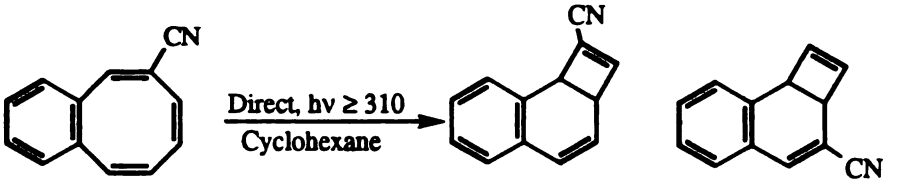
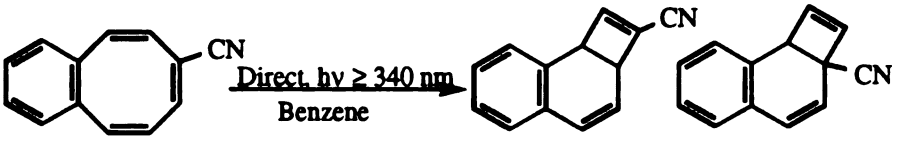


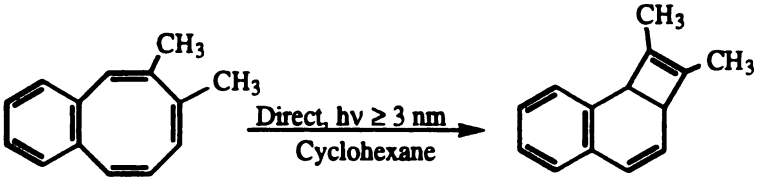
7 : 1



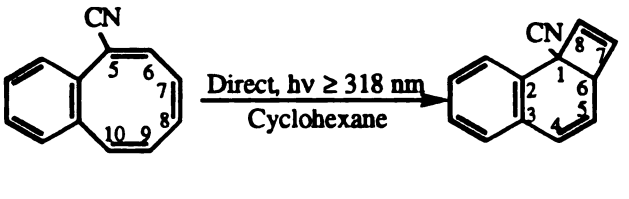
2.3 : 1



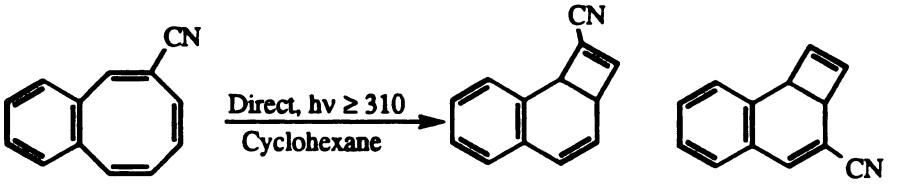
Sensitization gave no products 1 : 1



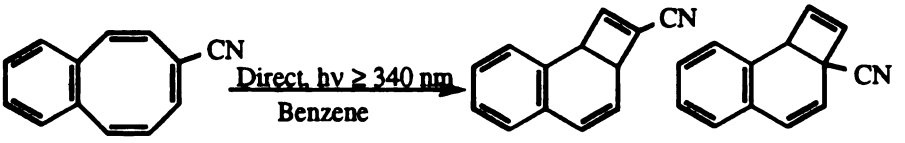
Scheme 36



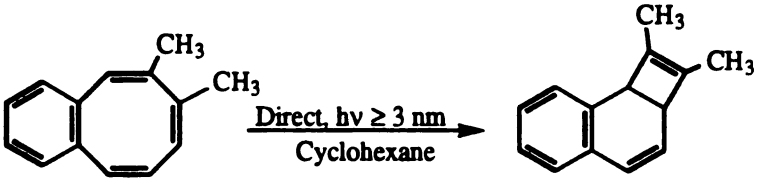
7 : 1



2.3 : 1

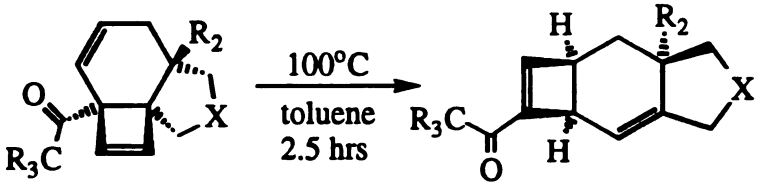


Sensitization gave no products 1 : 1



Scheme 36

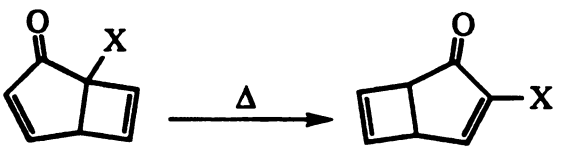
Wagner and Alehashem[28] found several examples in which the tricyclo[6.3.0.0^{1,4}]undeca-2,5-diene system was thermally transformed to the tricyclo[6.3.0.0^{3,6}]undeca-1,4-diene system at relatively low temperatures (Scheme 37).



R=F, H
X=C, O

Scheme 37

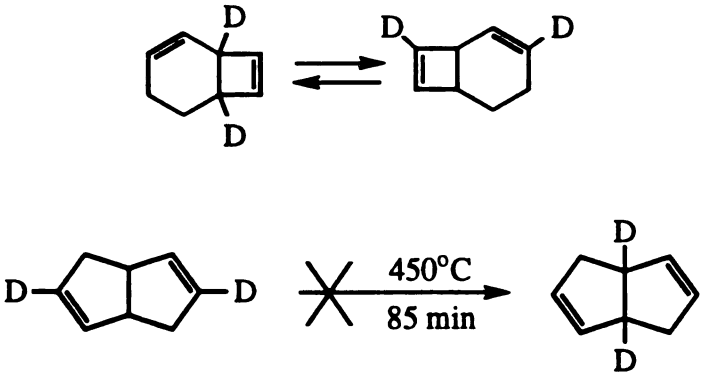
Mukai[77] and Kimura[78] found that 1-X-bicyclo[3.2.0]hepta-3,6-diene-2-one can be converted thermally into 3-X-bicyclo[3.2.0]hepta-3,6-diene-2-one. They suggested that these reactions proceed via the symmetry-allowed antara-antara Cope rearrangement (Scheme 38).



X= OMe, NHCOR

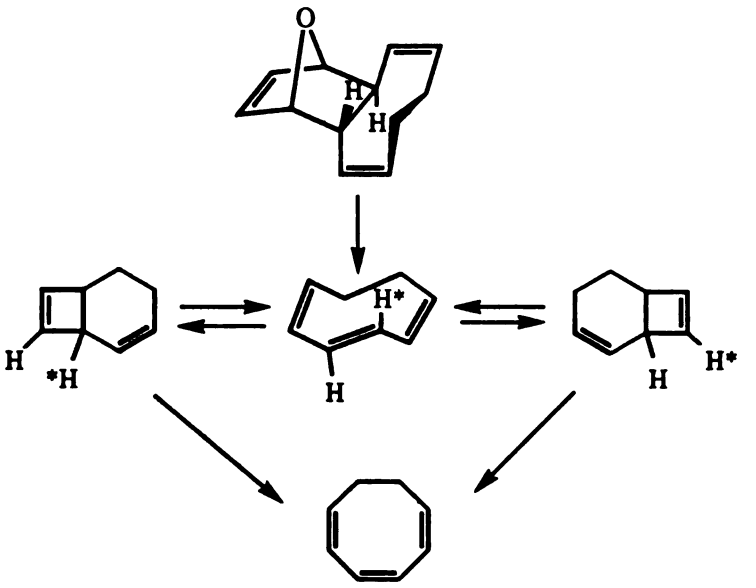
Scheme 38

Baldwin and Kaplan[79] pointed out that the Cope mechanism is rendered highly unlikely by the fact that a molecule constrained to react this way, 3,7-dideuteriobicyclo[3.3.0]octa-2,6-diene, does not rearrange in 85 min at 450°C. On the other hand, Baldwin found that deuterium-labeled bicyclo[4.2.0]octa-2,7-diene rearranges to the other isomer (Scheme 39).



Scheme 39

Baldwin[80] suggested that these rearrangements occurs through the formation of the cis, trans, cis cyclic trienes via the thermally allowed conrotatory opening of the cyclobutene ring. (This shows the importance of the cyclobutene moiety for production of the postulated triene intermediate).[81] The cyclic triene



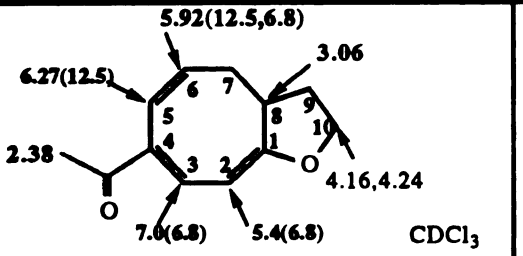
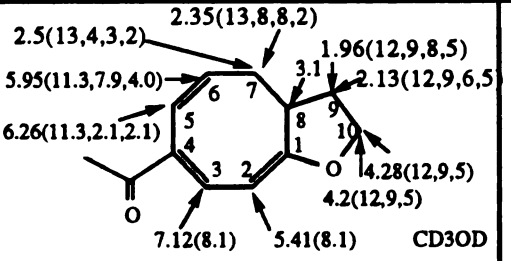
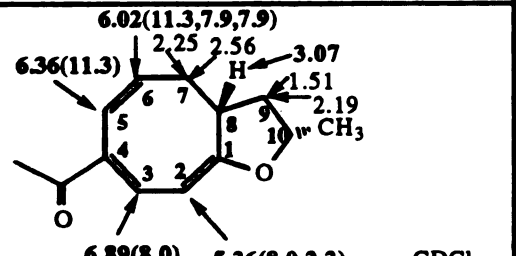
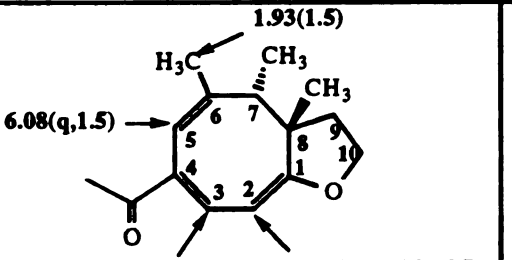
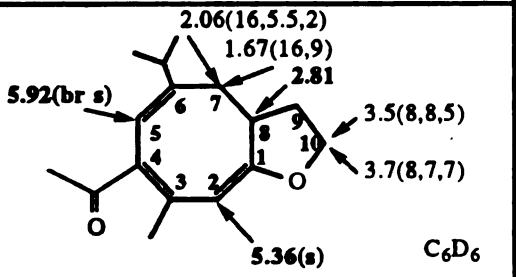
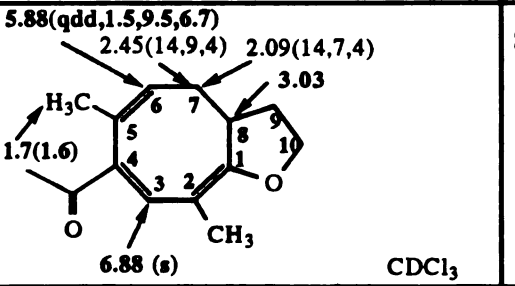
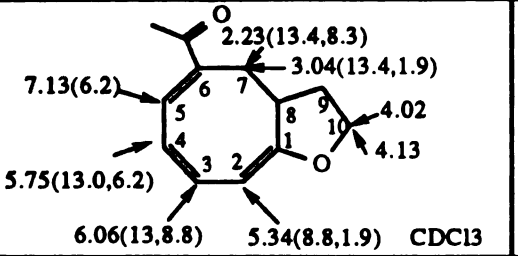
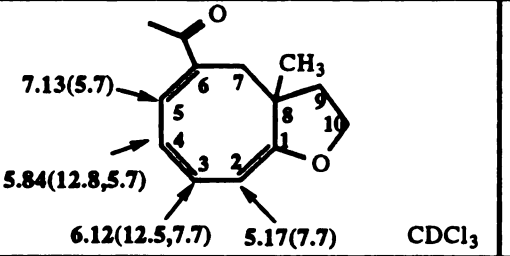
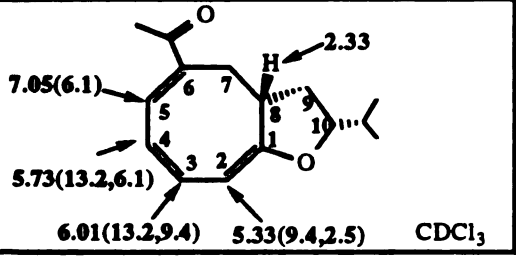
Scheme 40

will either revert to starting material or close on the other cis double bond to give the rearranged bicyclic structure. Kinetic studies showed that the cyclic triene rearranges to the bicyclic products which open thermally to all cis cyclooctatriene (Scheme 40).

^{1}H NMR Data For Some Photoproducts

In this work the regioselectivity for the [2+2] photocycloaddition reaction was studied. The remote double bond can add either syn or anti to the substituent ortho to the tether. Differentiation between the two modes of addition was done by ^{1}H NMR analysis. Thus, thorough understanding of the ^{1}H NMR spectra of similar systems is required. The following tables present key ^{1}H NMR data of some [2+2] cycloaddition products previously reported by other members of the Wagner research group. Product assignments depended heavily on comparison of NMR chemical shifts and coupling constants.

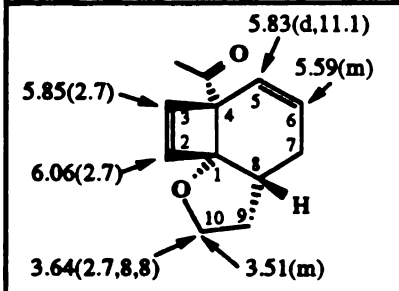
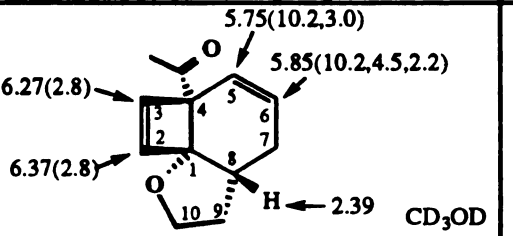
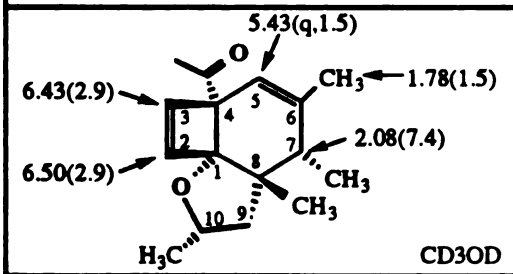
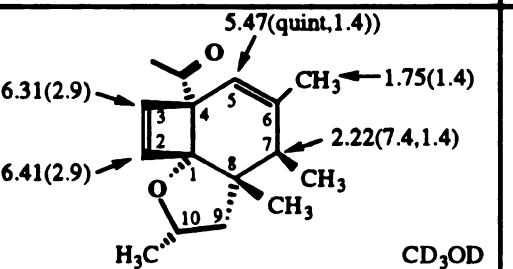
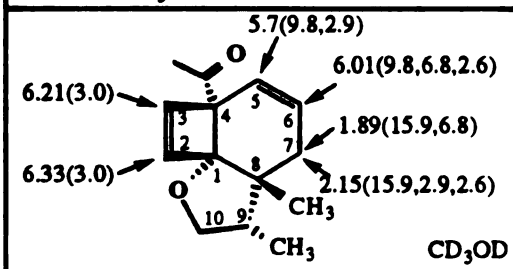
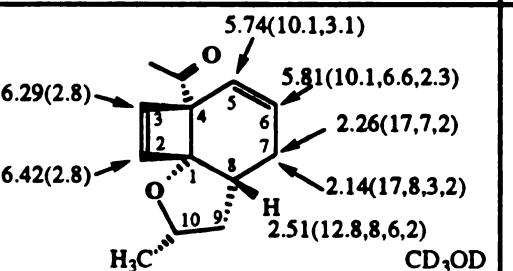
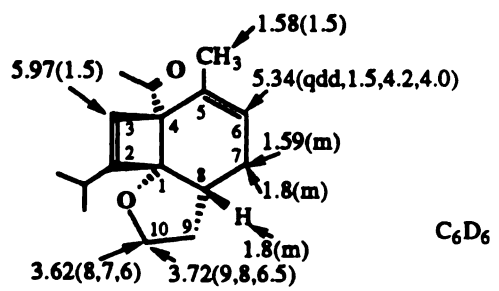
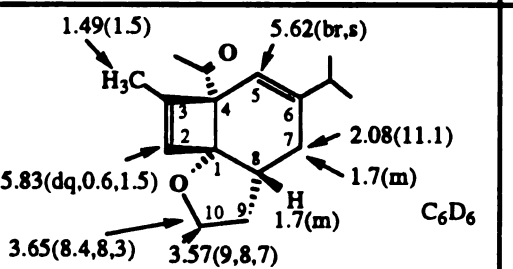
Table 2: Selected chemical shifts and coupling constants of some 4-acetyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**COT**) derivatives

Chemical Shifts[a](coupling constants)[b]	Ref.	Chemical Shifts[a] (coupling constants)[b]	Ref.
	18		82
	82		82
	83		83
	84		84
	82		

a: ppm

b: Hz

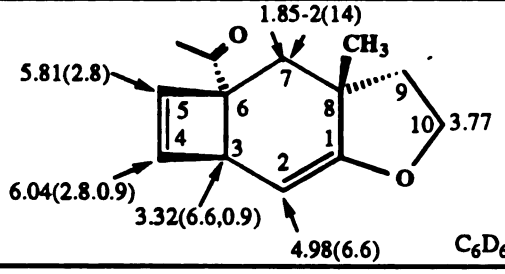
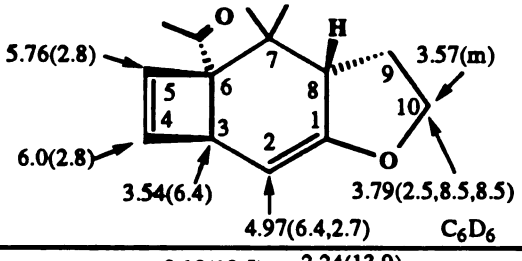
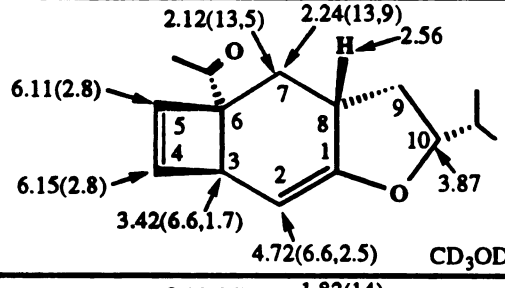
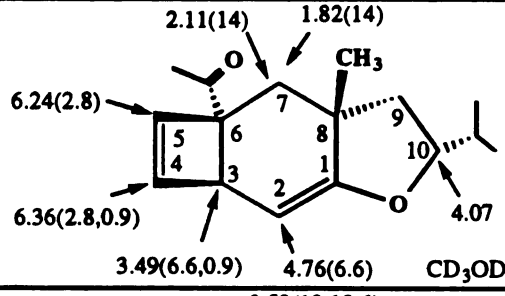
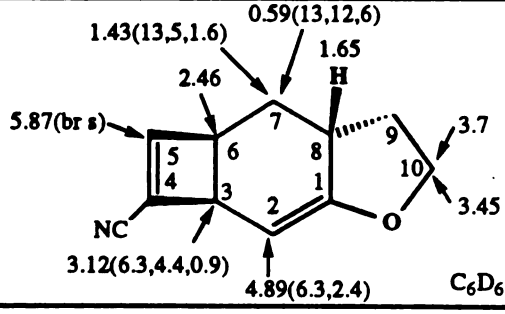
Table 3: Selected chemical shifts and coupling constants of some 4-acetyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**ACB**) derivatives

Chemical Shifts[a] (coupling constants)[b]	Ref.	Chemical Shifts[a] (coupling constants)b	Ref.
	84		82
	82		82
	82		82
	83		83

a: ppm

b: Hz

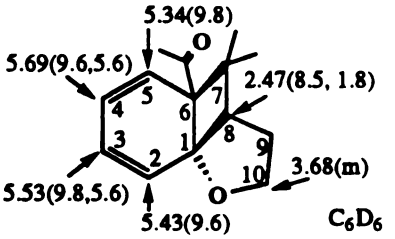
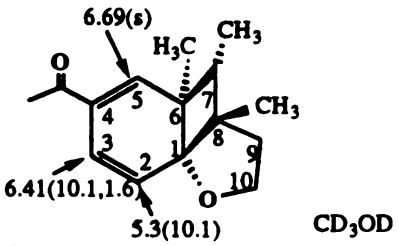
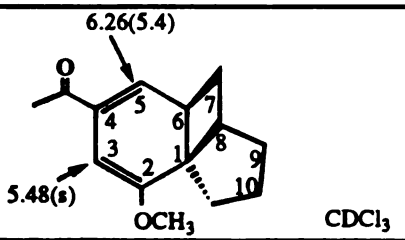
Table 4: Selected chemical shifts and coupling constants of some 4-acetyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**LCB**) derivatives

Chemical Shifts[a] (coupling constants)[b]	Ref.
	18
	84
	82
	20
	83

a: ppm

b:Hz

Table 5: Selected chemical shifts and coupling constants of some 4-acetyl-11-oxa-tricyclo[6.3.0.0^{1,6}]undeca-2,4-diene (**CHD**) derivatives

Chemical Shifts[a] (coupling constants)[b]	Ref.
	17
	82
	85

a: ppm

b: Hz

Table 2 presents selected chemical shifts and coupling constants of some 4-acetyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**COT**) derivatives. It shows that cis vinylic protons couple to each other with coupling constant about 11.0-13.5 Hz. Also H_2 couples to the bridgehead proton, H_8 with a coupling constant of 2.0~2.5 Hz.

Table 3 presents selected chemical shifts and coupling constants of some 4-acetyl-11-oxatricyclo[6.3.0.$0^{1,4}$]undeca-2,5-diene (**ACB**) derivatives. It shows that vinylic cyclobutene protons couple to each other with coupling constants of 2.7~3.0 Hz. On the other hand, vinylic cyclohexene protons couple to each other with about a 10 Hz coupling constant. Also, H_5 couples allylically to only one of the protons at C_7 with a coupling constant about 1.4-3.1 Hz.

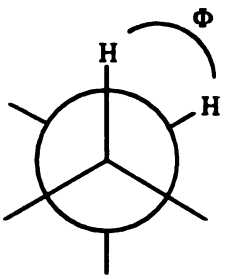
Table 4 presents selected chemical shifts and coupling constants of some 4-acetyl-11-oxatricyclo[6.3.0.$0^{3,6}$]undeca-1,4-diene (**LCB**) derivatives. Again, it shows that vinylic cyclobutene protons couple to each other with about a 2.8 Hz coupling constant. It also shows that H_2 couples allylically to H_8 with about 2.5 Hz and vicinally to H_3 with about 6.5 Hz coupling constants.

Conformational Analysis

Among the features that have made ^1H NMR one of the most useful tools in organic chemistry, the ability to apply vicinal proton-proton coupling constants to structural and stereochemical analysis. Karplus defined a mathematical relationship between $^3J_{H\text{-}C\text{-}C\text{-}H}$ and the H-C-C-H dihedral angle Φ. These calculations are approximate and do not take into account such factors as electronegative substituents, H-C-C bond angles, or bond lengths. The Karplus[86] rule is usually expressed by the following equations:

$$J_{H\text{-}C\text{-}C\text{-}H'} = 8.5 \cos^2 \Phi - 0.3 \quad 0^o < \Phi < 90^o$$

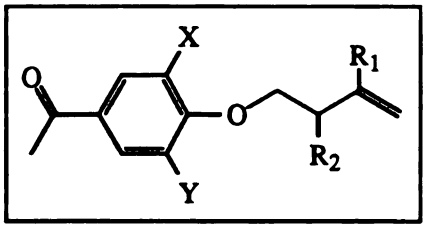
$$J_{H\text{-}C\text{-}C\text{-}H'} = 9.5 \cos^2 \Phi - 0.3 \quad 90^o < \Phi < 180^o$$



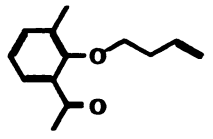
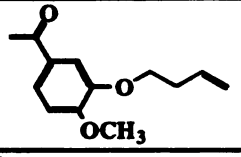
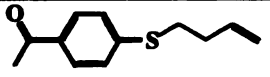
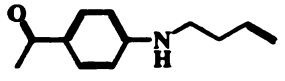
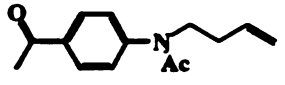
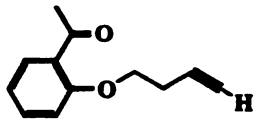
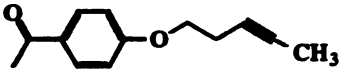
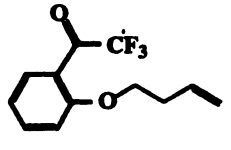
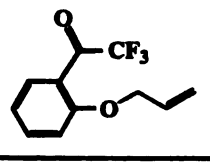
Geometry optimization can be done using several computational methods and levels. In this work, photoproduct structures were optimized at the semi-empirical level (AM1). From the dihedral angles, vicinal coupling constants were calculated by the Karplus equations. The best geometry and dihedral angles of various photoproducts and their coupling constants are described in the Results chapter.

RESULTS

In this work, several ring substituted alkenoxyacetophenones were prepared to study their regioselectivity of their photocycloaddition reaction. The effect of changing the tether anchor atom was also studied by replacing the oxygen with nitrogen and sulfur. Some alkynoxyacetophenones and trifluoromethyl derivatives were also studied. The structures and corresponding thesis notations are listed below.

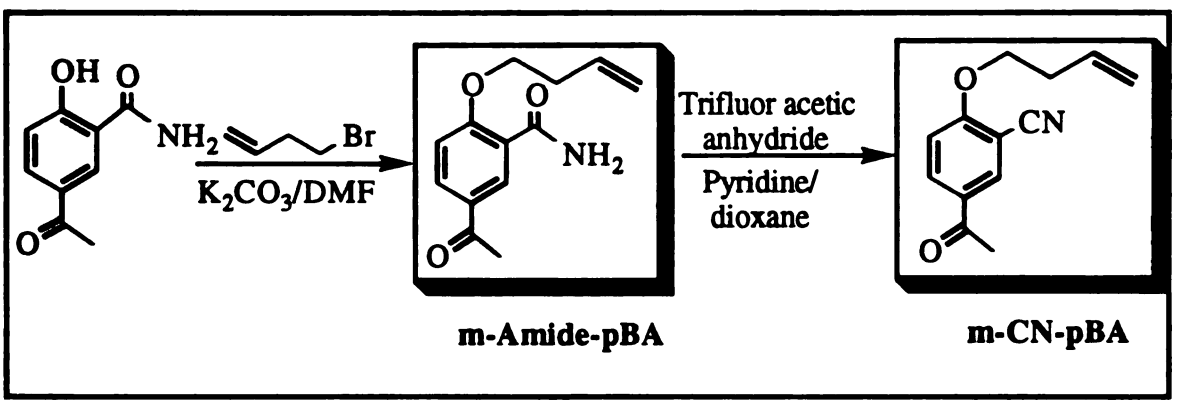


X	Y	R_1	R_2	Name	Thesis Notation
CH_3	H	H	H	4-(3-Buten-1-oxy)-3-methyl-acetophenone	**m-Me-pBA**
t-Bu	H	H	H	4-(3-Buten-1-oxy)-3-*t*-butyl-acetophenone	**m-^{t}Bu-pBA**
i-Pr	CH_3	H	H	4-(3-Buten-1-oxy)-3-isopropyl-5-methylacetophenone	**m-Me-iPr-pBA**
i-Pr	CH_3	H	CH_3	4-(2-Methyl-3-buten-1-oxy)-3-isopropyl-5-methylacetophenone	**m-Me-iPr-Me$_2$-pBA**
$CONH_2$	H	H	H	4-Acetyl-1-(3-buten-1-oxy) benzamide	**m-Amide-pBA**
COOMe	H	H	H	Methyl-5-acetyl-2-(3-buten-1-oxy) benzoate	**m-Est-pBA**
CN	H	H	H	4-(3-Buten-1-oxy)-3-cyano-acetophenone	**m-CN-pBA**
CF_3	H	H	H	4-(3-Buten-1-oxy)-3-trifluoromethylacetophenone	**m-CF$_3$-pBA**
OCH_3	H	H	H	4-(3-Buten-1-oxy)-3-methoxy-acetophenone	**m-OMe-pBA**
OCH_3	H	CH_3	H	4-(3-Methyl-3-buten-1-oxy)-3-methoxyacetophenone	**m-OMe-Me$_3$-pBA**
SCH_3	H	H	H	4-(3-Buten-1-oxy)-3-(methylmercapto)acetophenone	**m-SMe-pBA**

Compound	Name	Thesis Notation
	2-(3-Buten-1-oxy)-3-methyl-acetophenone	**m-Me-oBA**
	3-(3-Buten-1-oxy)-4-methoxy-acetophenone	**p-OMe-mBA**
	4-(3-Buten-1-mercapto)-acetophenone	**p-Thio-AP**
	4-(3-Buten-1-amino)acetophenone	**p-NH-AP**
	*N*-Acetyl-4-(3-buten-1-amino)-acetophenone	**p-NAc-AP**
	2-(3-Butyn-1-oxy)acetophenone	**o-Ac-TB-H**
	4-(3-Pentyn-1-oxy)acetophenone	**p-Ac-TB-Me**
	2-(Buten-1-oxy) α,α,α-trifluoro-acetophenone	**o-BTFAc**
	2-(Propen-1-oxy) α,α,α-trifluoro-acetophenone	**o-PTFAc**

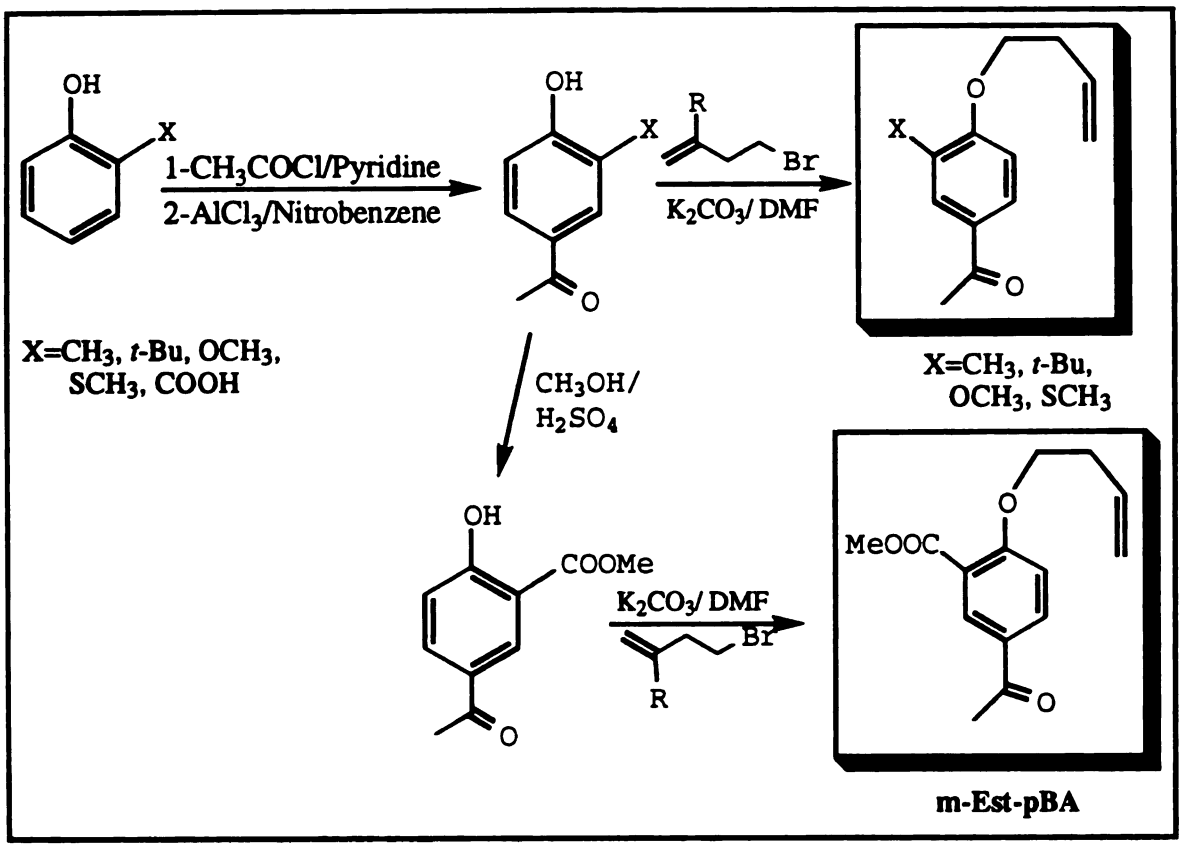
Preparation of Acetophenones

m-Amide-pBA was prepared by the direct coupling of 5-acetyl-2-hydroxybenzamide with 4-bromo-1-butene in dry DMF. Dehydration of the product using trifluoroacetic anhydride/pyridine mixture gave **m-CN-pBA** in 72% yield (Scheme 41).



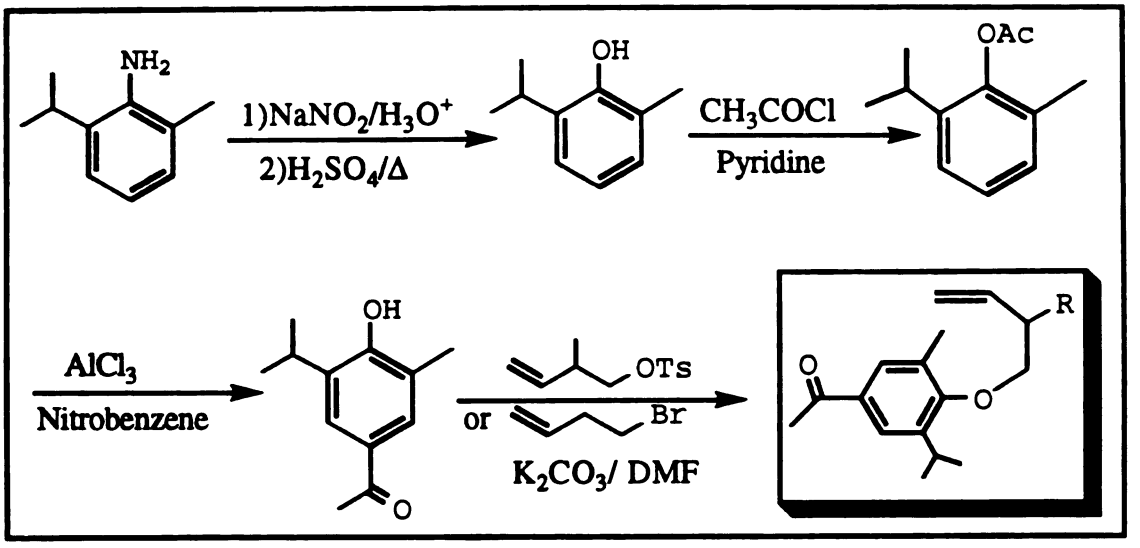
Scheme 41

m-Me-pBA, **m-^{t}Bu-pBA**, **m-OMe-pBA** and **m-SMe-pBA** were prepared by Fries rearrangement of their corresponding acetates in nitrobenzene followed by coupling with the alkenyl halide in DMF. For **m-Est-pBA**, 5-acetylsalicylic acid was esterified before coupling with the alkenyl halide (Scheme 42).



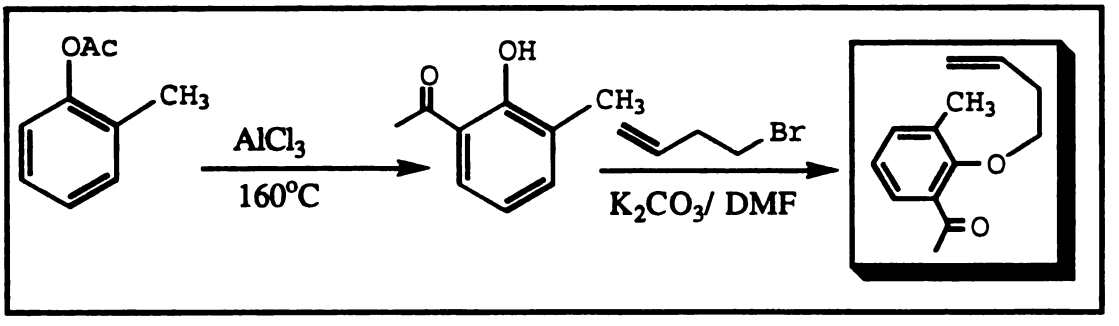
Scheme 42

m-Me-^{i}Pr-pBA and **m-Me-^{i}Pr-Me2-pBA** were prepared by diazotizing and hydrolyzing 2-isopropyl-6-methylaniline. The resulting phenol was acylated using acetyl chloride and pyridine, followed by Fries rearrangement (anhydrous aluminum chloride, room temperature) to the corresponding acetophenone. Etherification gave the final products (Scheme 43).



Scheme 43

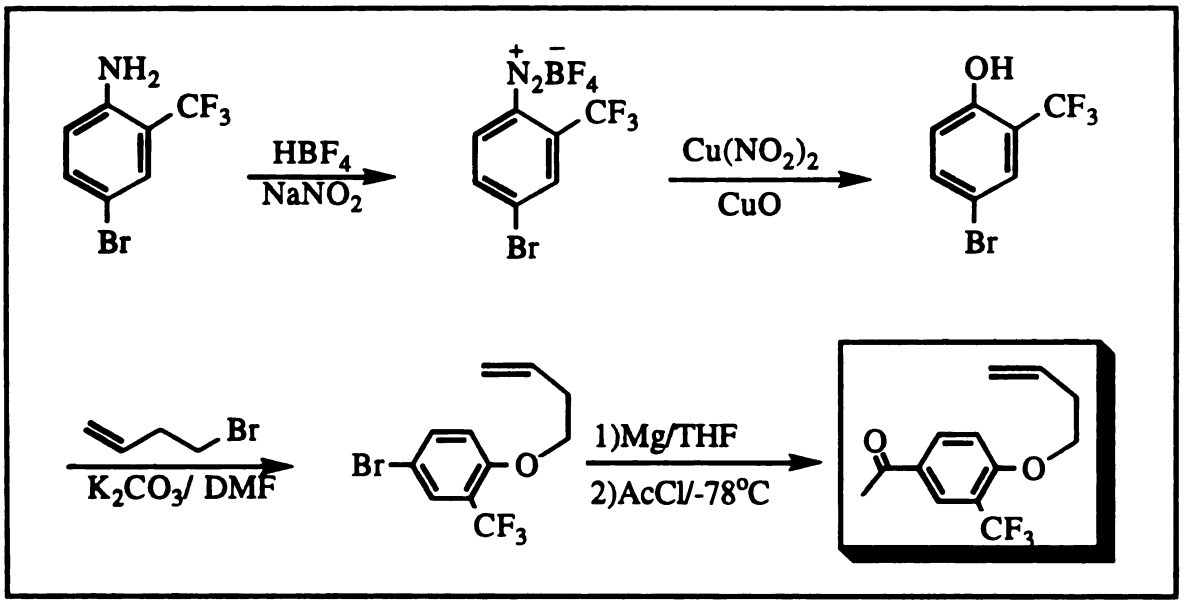
m-Me-oBA was prepared by treating o-methylphenyl acetate with anhydrous aluminum chloride and heating at 160°C. The resulting compound, 2-hydroxy-3-methylacetophenone was etherified with 4-bromo-1-butene (Scheme 44).



Scheme 44

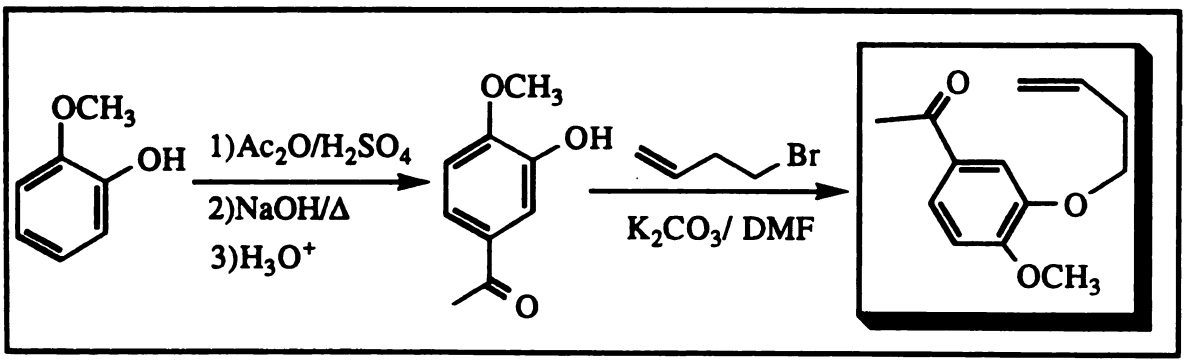
m-CF_3-pBA was prepared by diazotizing and hydrolyzing 4-bromo-α,α,α-trifluoro-*o*-toluidine. The resulting phenol was coupled to 4-bromo-1-butene in DMF to give 5-bromo-2-(3-buten-1-oxy)-α,α,α-trifluorotoluene which

was reacted with magnesium and quenched with acetyl chloride to give the final product (Scheme 45).



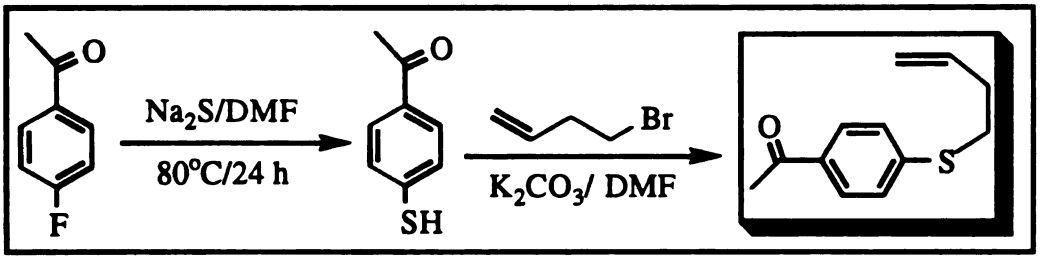
Scheme 45

p-OMe-mBA was prepared by acylating guaiacol by a mixture of acetic anhydride and sulfuric acid. The resulting compound, 3-acetoxy-4-methoxy-acetophenone, was hydrolyzed with sodium hydroxide to give 3-hydroxy-4-methoxyacetophenone which was etherified with 4-bromo-1-butene to give the final product (Scheme 46).



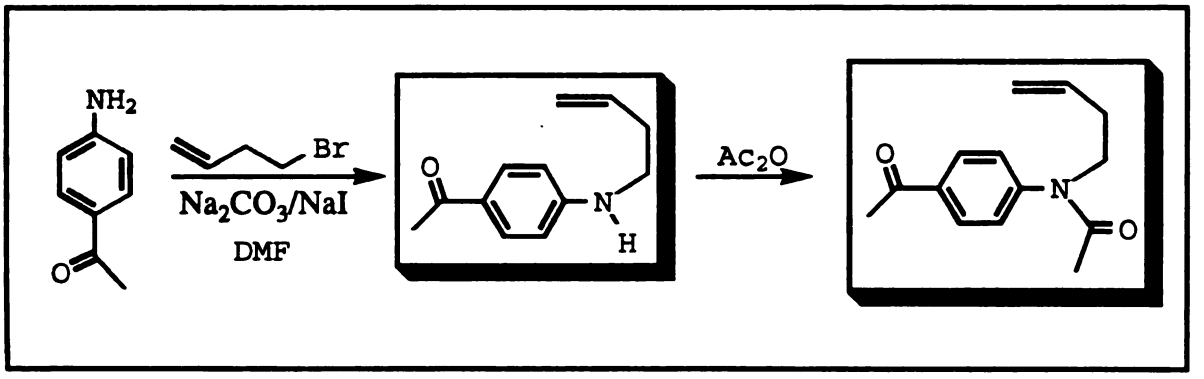
Scheme 46

p-Thio-AP was prepared by reacting 4-fluoroacetophenone with excess sodium sulfide in DMF. The resulting product, 4-mercaptoactophenone was reacted with 4-bromo-1-butene to give the final product (Scheme 47).



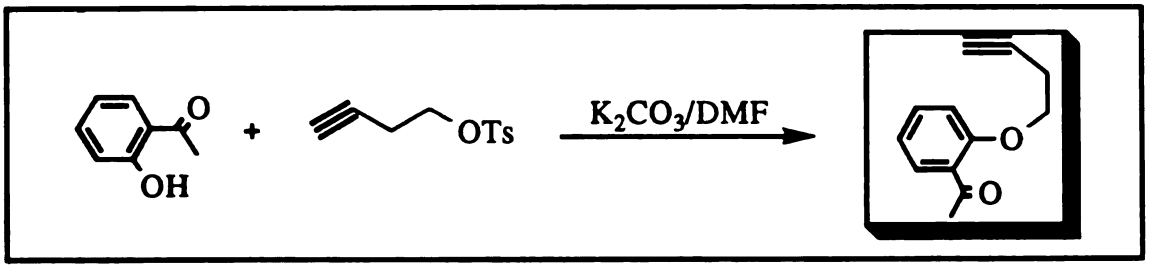
Scheme 47

p-NH-AP was prepared by coupling 4-aminoacetophenone with 4-bromo-1-butene in DMF. The resulting amine, **p-NH-AP**, was acylated with acetic anhydride to give **p-NAc-AP** (Scheme 48)



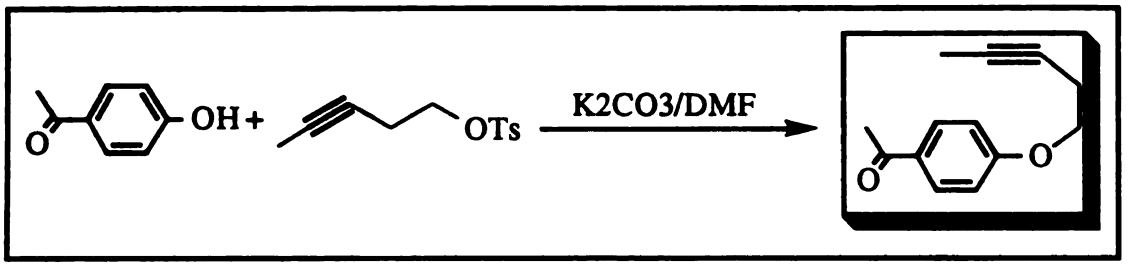
Scheme 48

o-Ac-TB-H was prepared by coupling *o*-hydroxyacetophenone with 3-butynyl-1-tosylate in DMF (Scheme 49).



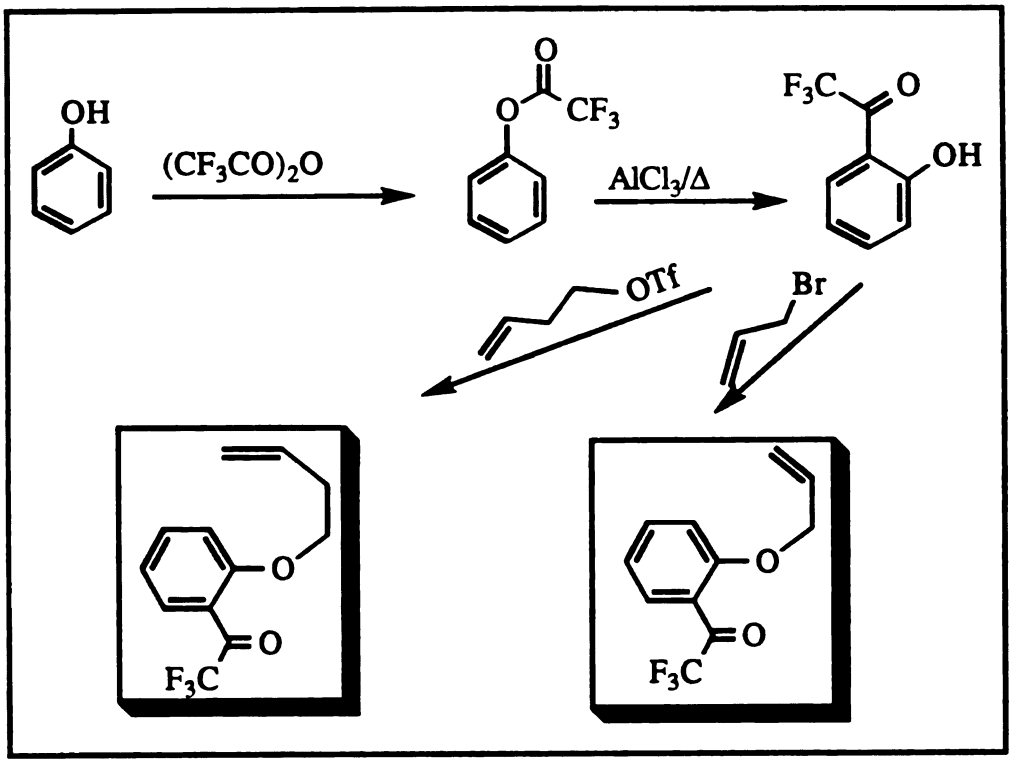
Scheme 49

p-Ac-TB-Me was prepared by coupling *p*-hydroxyacetophenone with 3-pentynyl-1-tosylate (Scheme 50).



Scheme 50

o-BTFAc was prepared by reacting phenol with trifluoroacetic anhydride to give phenyl trifluoroacetate. This was reacted with anhydrous aluminum chloride at 100°C to give 2-hydroxy-α,α,α-trifluoroacetophenone which was coupled with 3-buten-1-triflate to give the final product. Alternatively, 2-hydroxy-α,α,α-trifluoroacetophenone could be coupled with allyl bromide to give **o-PTFAc** (Scheme 51).



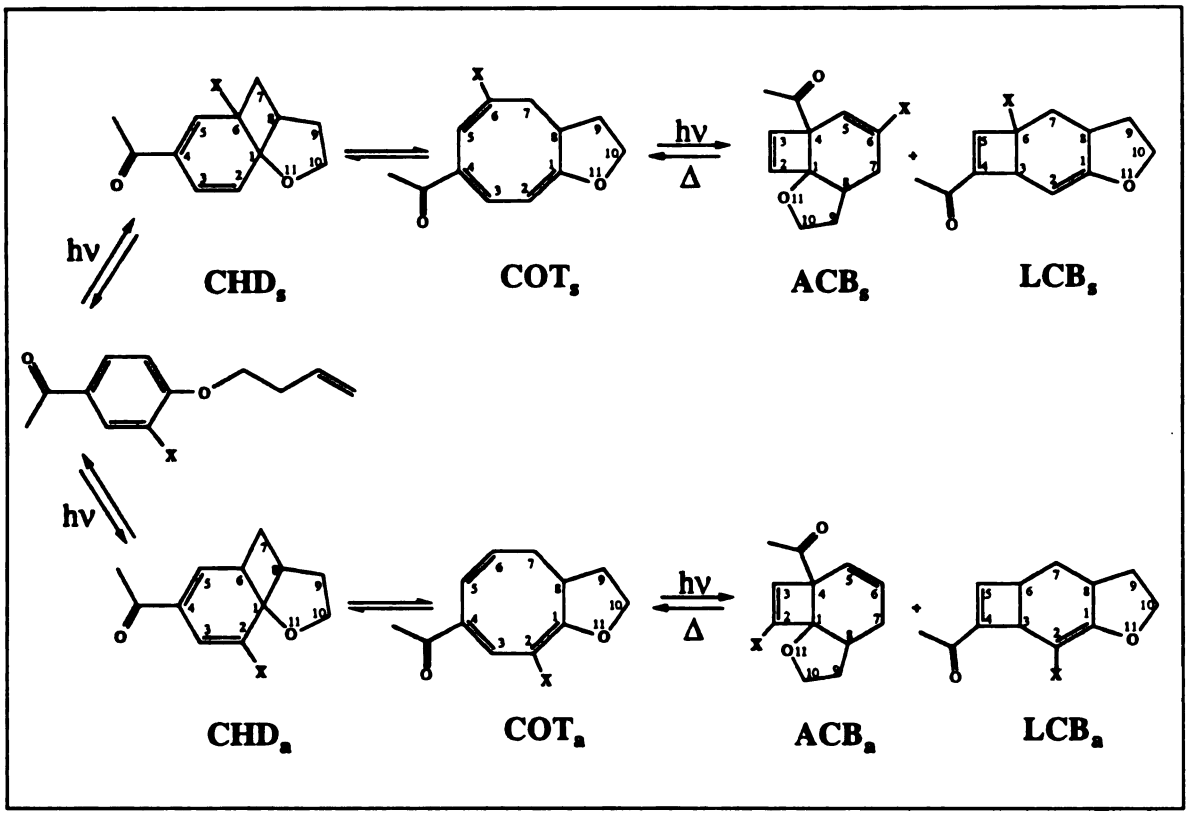
Scheme 51

Photocycloaddition and Identification of Photoproducts

Ketone solutions in deuterated methanol or benzene were irradiated in an NMR tube, with medium pressure mercury arc filtered through Pyrex so as to cut off any wavelength below 290 nm. In some cases filtered wave lengths of 313, 365 or > 334 nm were used for irradiation. ^{1}H NMR spectroscopy was used to follow the reaction course. If the NMR spectra were taken immediately after irradiation, 4-acetyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**Linear CycloButene, LCB**) and/or 4-acetyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**Angular CycloButene, ACB**) derivatives were generally observed as the final photoproducts . Large scale irradiations were performed using ~0.3 gm of ketone in argon-bubbled methanol or benzene. In some cases, unstable photoproducts were identified using their partial ^{1}H NMR because of the broadening of the NMR signals that may be attributed to the formation of some polymeric byproducts.

Irradiation of *p*-alkenoxy-*m*-substituted acetophenone may lead to two primary cycloaddition products. In one of them, the double bond adds to the benzene ring towards (syn, **s**) the substituent to give 4-acetyl-11-oxatricyclo[6.3.0.0^{1,6}]undeca-2,4-diene derivatives (**CycloHexaDiene, CHD$_s$**), while for the other isomer, the double bond adds away (anti, **a**) from the substituent to give the cyclohexadiene derivatives (**CHD$_a$**). Due to thermal rearrangement, 4-acetyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene derivatives (**CycloOctaTreiene, COT$_s$** or **COT$_a$**) are formed. Further photochemical reactions lead to **ACB** and/or **LCB** (Scheme 52). This means that one or more of eight different isomers are expected to be formed after irradiation. These isomers were identified from each other by ^{1}H NMR spectroscopy. Taking advantage of the fact that vinylic coupling constants depend on ring size[87,88] and that chemical shifts depend on

the environment around the protons[88] allowed us to identify each of the formed isomeric products by their unique ^1H NMR spectrum. In some cases homonuclear decoupling and ^1H NMR peak simulation were used to help in



Scheme 52

determining the coupling constants. Nuclear Overhauser effect (nOe) experiments were used to determine the stereochemistry of the products when possible. Semi-empirical quantum mechanical calculations (AM1) were used to calculate the best geometry for some of the isomers allowing an estimate of the dihedral angle between protons. This helped to predict coupling constants and compare them to the experimental ones.

If the double bond adds to the benzene ring syn to the meta substituent, the primary photoproduct **CHD$_S$** will have three vinylic protons. The ^1H NMR spectrum is expected to show H_5 as a singlet at ~6.5-7.0 ppm due to conjugation

with the acetyl group. H_2 and H_3 are expected to appear at 5.5 and 6.4 ppm, respectively, with a coupling constant about 10.0 Hz. On the other hand, if the double bond adds anti to the substituent, the primary photoproduct **CHD$_a$** is expected to have only two olefinic protons. H_5 is expected to be a doublet (J~5.5 Hz) at about 6.5-7.0 ppm while H_3's chemical shift and coupling constant would be dependent upon the substituent at C_2.

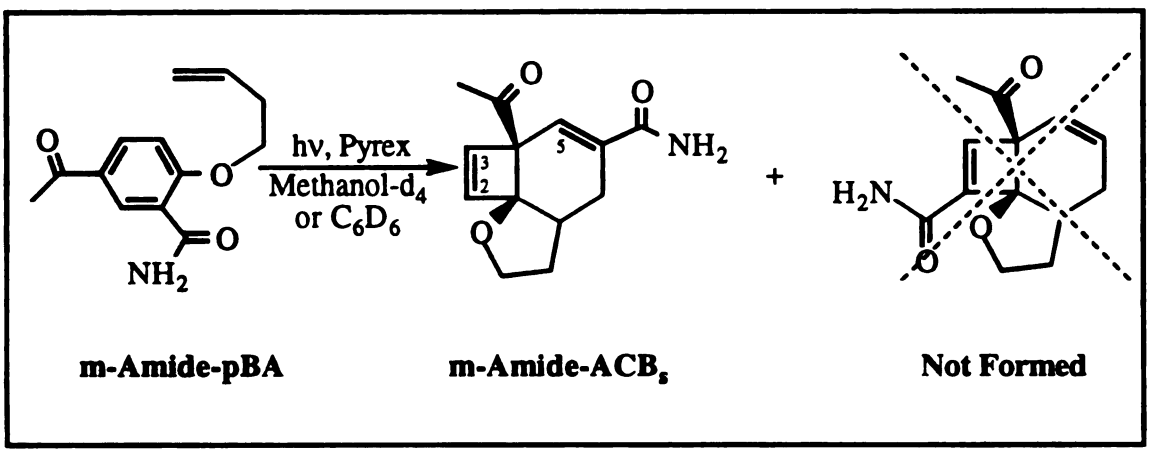
Thermal ring opening of **CHD** results in the formation of **COT**. **COT$_s$** has three olefinic protons. H_2 is expected to appear at 5.0-5.5 ppm due to its enol ether character. It also expected to couple allylically to H_8 with a *J* value about 2.5 Hz and couple vicinally to H_3 with coupling constant about ~7.0-9.0 Hz. H_3 is expected to be a doublet at 6.5-7.0 ppm. H_5's coupling constant and chemical shift will vary depending on the substituent at C_6. **COT$_a$** also has three olefinic protons. H_3 is expected to be a singlet at 6.6-7.0 ppm. H_5 and H_6 are expected to appear at about 6.3 and 5.9 ppm, respectively, and couple to each other with a *J* value about 11.5-13.5 Hz. They also couple to $H_{7\alpha}$ and $H_{7\beta}$.

COT reacts photochemically to give either **ACB** or **LCB**. **ACB$_s$** has three olefinic protons. H_2 and H_3 are expected to appear at about 5.9-6.50 ppm and couple to each other with *J* ~2.9 Hz. H_5's chemical shift depends on the C_6 substituent. It is expected to couple allylically to only one of the protons at C_7 (c.f. table 3). **ACB$_a$** also has three olefinic protons. H_5 and H_6 are expected to appear at 5.6-6.0 ppm and to couple to each other with a *J* value about 10.0 Hz. H_5 is also expected to couple to one of the protons at C_7 while H_6 couples to both protons at C_7.

LCB$_s$ has only two olefinic protons. H_5 is expected to be a singlet at about 6.5-7.0 ppm while H_2 is expected to appear at 5.0-5.5 ppm because of its enol ether character. It is expected to couple allylically to H_8 with a J value about 2.5 Hz. It is also expected to couple to H_3. If the molecule has H_8 syn to the

cyclobutene ring then $J_{2,3}$ is expected to be about 5.5-6.6 Hz while if H_8 is anti to the cyclobutene ring then $J_{2,3}$ is expected to be about 2.3 Hz (cf. table 8). Alternatively, **LCB_a** has only one vinyl proton (H_5). It is expected to be a doublet at about 6.5-7.0 ppm and couple to H_6 with $J_{5,6}$ about 1.0 Hz.

Photochemistry of **m-Amide-pBA**



Scheme 53

A CD_3OD solution of **m-Amide-pBA** in an NMR tube was taped to an immersion well and irradiated for one hour using Pyrex filtered light ($\lambda \geq 290$ nm). Immediately after irradiation, the solution was colorless. A yellow color started to develop after a few minutes. ^1H NMR analysis showed the formation of two products; 4-acetyl-6-amido-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Amide-COT_S**) and 4-acetyl-6-amido-11-oxatricyclo[6.3.0.$0^{1,4}$]undeca-2,5-diene (**m-Amide-ACB_S**) in a ratio of 1 : 1. ^1H NMR showed that the ratio became 1.3 : 1 twenty five minutes after the irradiation, and 1.8 : 1 after thirty five minutes. **m-Amide-ACB_S** was totally converted to **m-Amide-COT_S** when the sample was left overnight at room temperature in the dark. Preparatory scale photolysis (1.0 gm of the ketone in 500 ml dry methanol) was carried out to isolate the

photoproduct. The mixture was purified by column chromatography (silica gel, 40% ethyl acetate/hexanes) to give 0.3 gm of 4-acetyl-6-amido-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Amide-COT$_S$**).

To obtain a pure sample of **m-Amide-ACB$_S$**, **m-Amide-pBA** in CD_3OD in NMR tube, degassed, and irradiated for 5 hours. ^1H NMR at -70°C (to slow down rearrangement of **Amide-ACB$_S$** to **Amide-COT$_S$**) showed that **m-Amide-ACB$_S$** has three olefinic protons; a doublet (J = 2.78 Hz) at 6.31 ppm (H_3), a doublet of doublets (J = 2.78, 0.6 Hz) at 6.48 ppm (H_2) and a doublet (J = 2.88 Hz) at 6.58 ppm (H_5). This pattern can only be achieved if the double bond of **m-Amide-pBA** adds to the benzene ring towards the amide group. If the double bond adds away from the substituent, the cyclobutene(s) formed would have only one olefinic proton and the cyclohexene ring would have two olefinic protons coupled to each other with a J value about 10 Hz.

The cyclooctatriene **m-Amide-COT$_S$** also has three olefinic protons; a doublet (J = 8.51 Hz) at 7.3 ppm (H_3), a singlet at 7.16 ppm (H_5) and a doublet of doublets (J = 8.51, 2.01 Hz) at 5.49 ppm (H_2). H_3 and H_5 appear at relatively high field due to their conjugation with electron-withdrawing groups while H_2 is at lower field because of its enol-ether character. This supports the observation that the double bond adds towards the amide group, since this spectrum does not agree with that expected for the cyclooctatriene resulting from addition of the double bond away from the amide group

Irradiation of **m-Amide-pBA** was also performed in benzene-d_6 (Scheme 54). ^1H NMR showed the formation of **m-Amide-ACB$_S$** as the only product. The other regioisomer was not detected by NMR. Also noticed was that **m-Amide-ACB$_S$** did not isomerize to **m-Amide-COT$_S$** during the NMR experiment as when methanol was employed as solvent. ^1H NMR of **m-Amide-ACB$_S$** showed also the

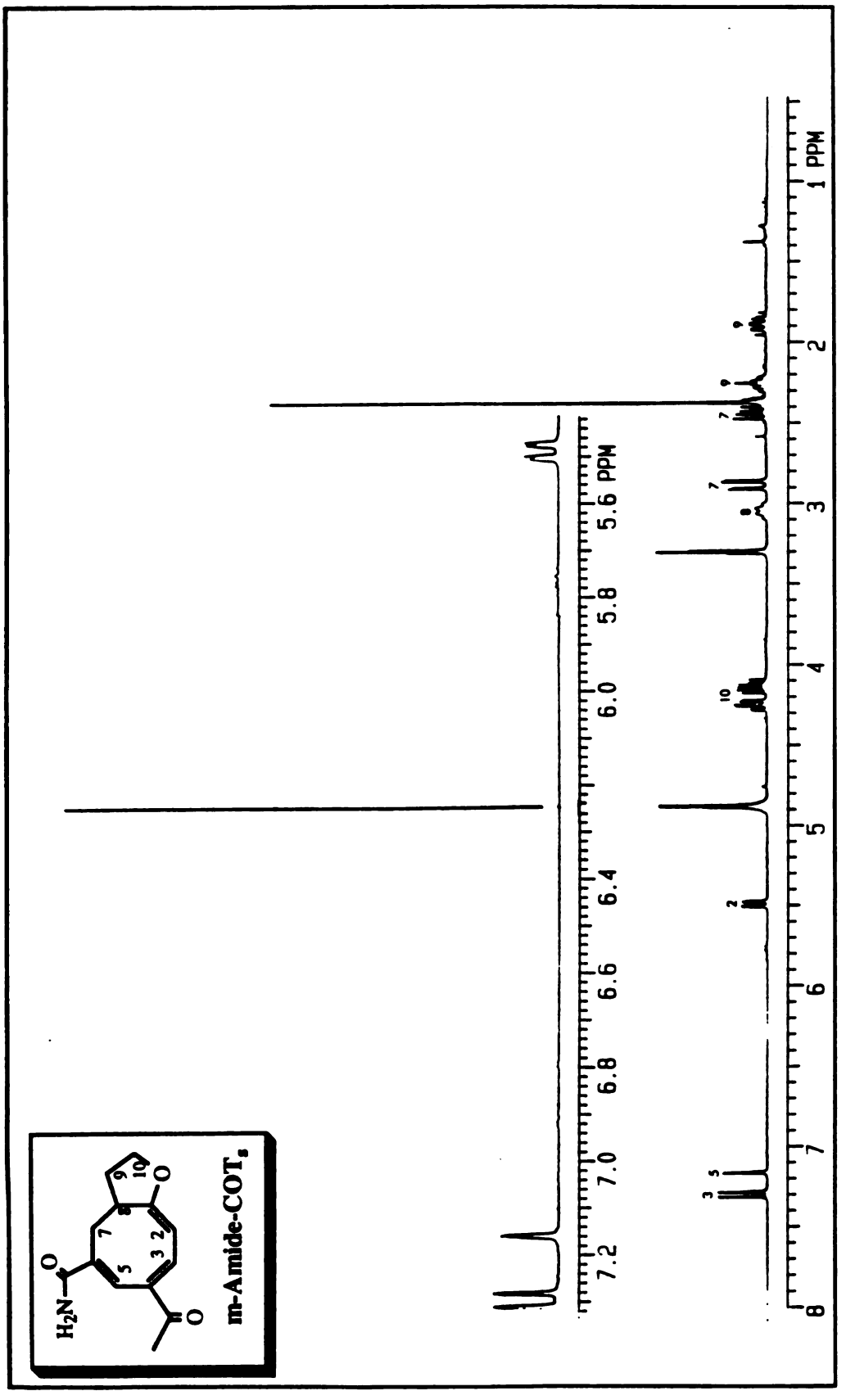
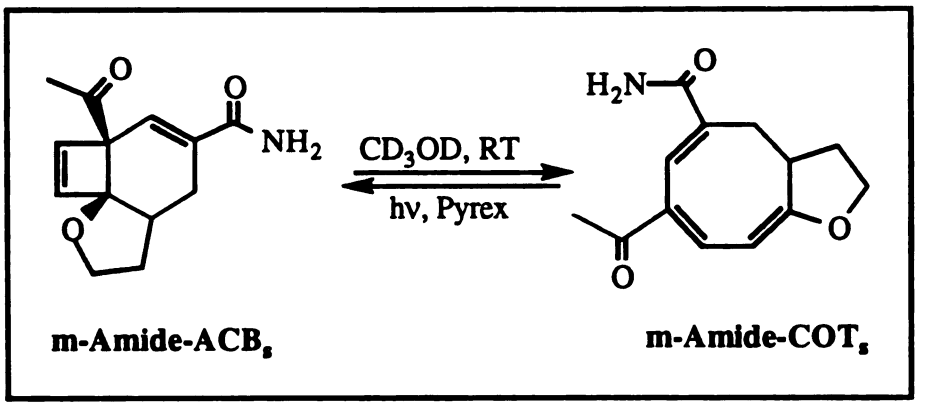


Figure 1: ^{1}H NMR spectrum of **m-Amide-COT$_s$** in methanol-d_4

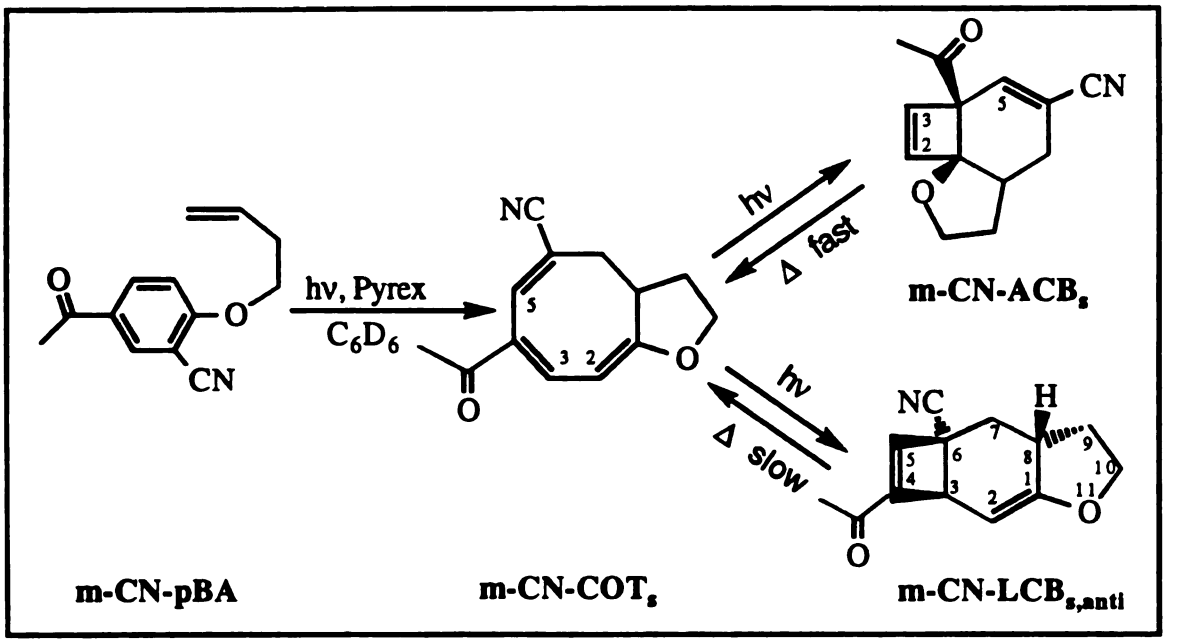
presence of three olefinic protons. Chemical shifts in benzene were; 5.6 ppm (H_3), 5.97 ppm (H_2) and 6.23 ppm (H_5).



Scheme 54

When **m-Amide-ACB$_S$** in CD3OD was left overnight at room temperature the sample color turned yellow. ^{1}H NMR showed the complete disappearance of **m-Amide-ACB$_S$** peaks and the formation of **m-Amide-COT$_S$**. Irradiation of the resulting solution using Pyrex-filtered light led to quantitative formation of **m-Amide-ACB$_S$**.

Photochemistry of m-CN-pBA



Scheme 55

In an NMR tube, a solution of **m-CN-pBA** in benzene-d_6 was irradiated with Pyrex filtered light ($\lambda \geq 290$ nm). After 60 minutes irradiation, ^{1}H NMR analysis showed that the starting ketone had been totally consumed. New sets of peaks were formed corresponding to two products: 4-acetyl-6-cyano-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-CN-LCB$_{s,anti}$**) and 4-acetyl-6-cyano-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-CN-ACB$_s$**) in a ratio of 3.5 : 1.0, respectively. When the sample was left at room temperature in the dark for one week, ^{1}H NMR showed the formation of new peaks which are due to the formation of 4-acetyl-6-cyano-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-CN-COT$_s$**)

Another sample of **m-CN-pBA** was irradiated at 313 nm. At the early stage of irradiation (17 minutes, 2% conversion), **m-CN-COT$_s$** was the only product detected by ^{1}H NMR spectroscopy. After 1 h, 45 min, ^{1}H NMR showed a mixture

of three products; **m-CN-COT$_S$**, **m-CN-ACB$_S$** and **m-CN-LCB$_{S,anti}$** in a ratio of 1.2 : 2.0 : 23.0. After about 4 hours irradiation, **m-CN-COT$_S$** disappeared totally.

Preparative scale photolysis (0.3 gm of **m-CN-pBA** in 250 ml of dry benzene) was carried out in order to isolate the photoproduct. After solvent evaporation, the mixture was separated by column chromatography to give 0.02 gm of **m-CN-pBA**, 0.03 gm of **m-CN-LCB$_{S,anti}$** and 0.085 gm of **m-CN-COT$_S$**.

^{1}H NMR and ^{13}C NMR spectra of the isolated **m-CN-COT$_S$** (in benzene-d_6) agree with the proposed structure and show that the double bond in **m-CN-pBA** adds to the benzene ring towards the substituent (cyano group). The cyclooctatriene which would arise from the addition of the double bond away from the substituent could not be detected.

The structure of **m-CN-LCB$_{S,anti}$** was determined by ^{1}H NMR analysis ($CDCl_3$). The two olefinic protons appear as a singlet at δ 6.63 ppm (H_5) and a dd at 5.0 ppm (H_2) (J = 6.4, 2.45 Hz). The two bridgehead protons appear at 2.35 ppm (H_8) (multiplet) and 3.9 ppm (H_3) (d, J = 6.6 Hz). The relatively large 2.45 Hz allylic coupling between H_2 and H_8 is due to a dihedral angle of 85^o between H_8-C_8-C_1-C_2 (AM1 calculation) indicating that the C_8-H_8 bond is parallel to the π orbital of C_1-C_2 bond.[90] To check whether H_8 is syn or anti to H_3, the dihedral angle H_2-C_2-C_3-H_3 was calculated for both isomers using AM1 semi-imperical calculation. The result showed an angle of 30^o for the anti isomer and 60^o for the syn isomer. Coupling constants were calculated using the Karplus equation as 6.0 Hz for the anti and 1.8 Hz for the syn. Experimental results showed that $J_{2,3}$ = 6.5 Hz (cf. table 8). This result suggested that the product has the anti configuration. An nOe experiment supported this result. Irradiation of the bridgehead proton at C_8 (2.35 ppm) induced enhancements of $H_{9\beta}$ (2.96%), H_5 (2.3%), $H_{10\beta}$ (1.5%) and $H_{7\beta}$ (0.32%). Similarly irradiation of H_5 (6.53 ppm) led to the enhancement of H_8 (3.02%) and $H_{7\beta}$ (1.37%).

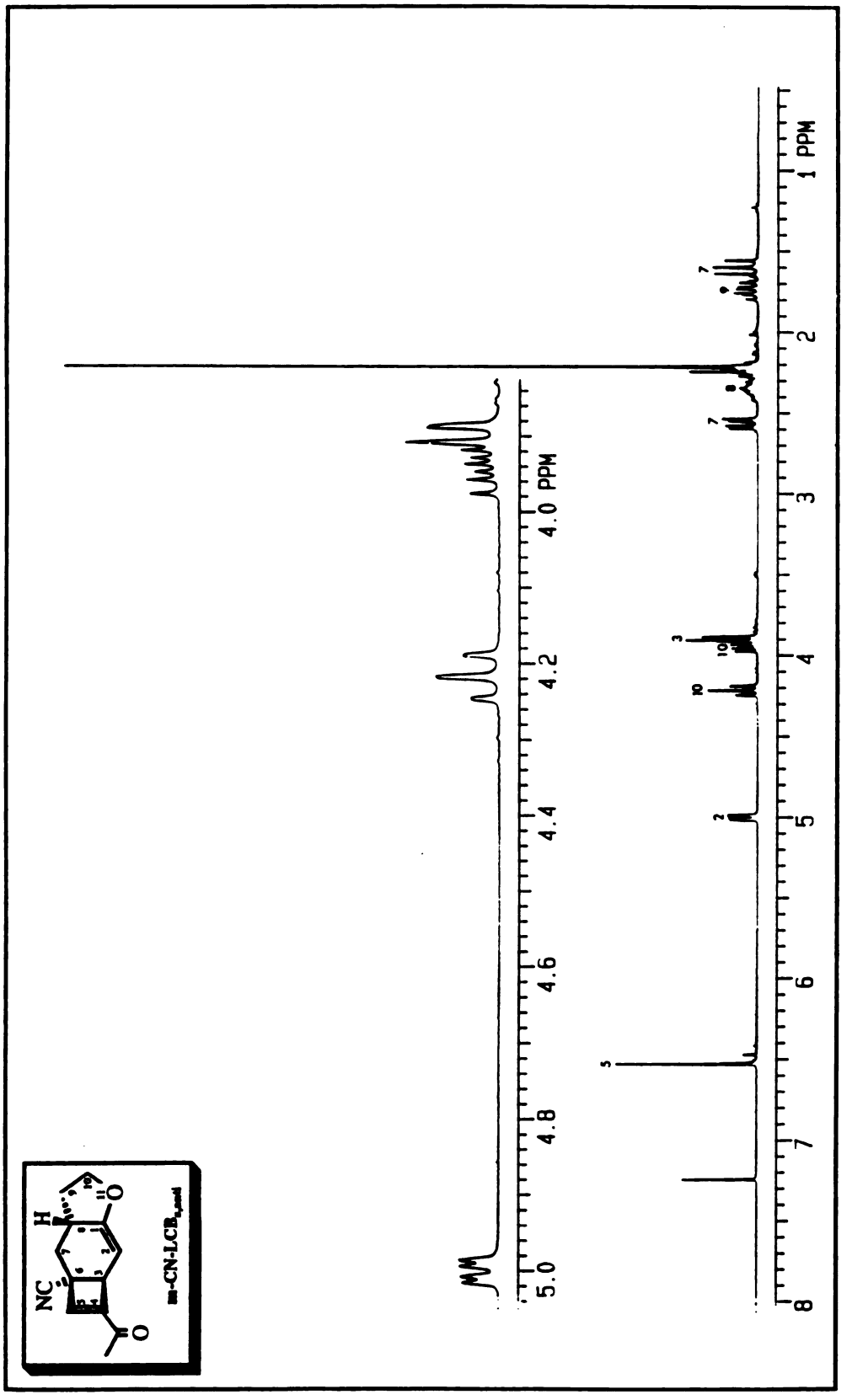
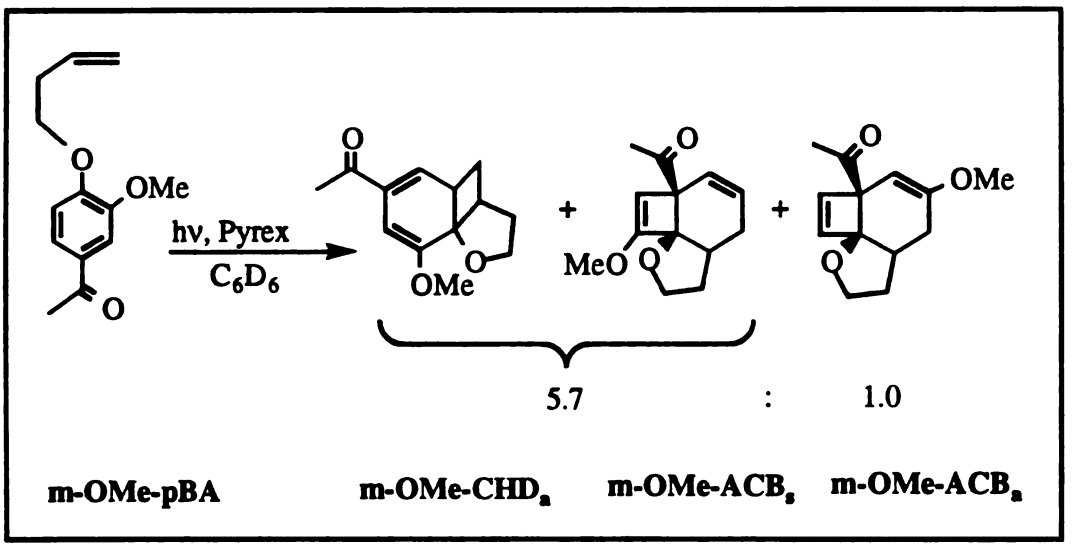


Figure 2: ^{1}H NMR spectrum of **m-CN-LCB$_{s,anti}$** in chloroform-*d*.

The other cyclobutene **m-CN-ACB$_S$** was neither isolated nor produced in pure form, but it was identified by comparing its ^{1}H NMR spectrum (olefinic region) with that of **m-Amide-ACB$_S$**. The partial spectrum of **m-CN-ACB$_S$** in benzene-d_6 is: δ 5.37 (d, J = 2.8 Hz, 1H) 5.80 (dd, J = 2.8, 0.5 Hz, 1 H) and 6.34 (broad d, J = 2.8 Hz, 1 H). For **m-Amide-ACB$_S$** it is: (benzene-d_6) δ 5.6 (d, J = 2.8 Hz, 1H) 5.97 (dd, J = 2.8, 0.6 Hz, 1H) and 6.23 (broad d, J = 2.8 Hz, 1H). These data suggest that the two compounds have similar structures.

Photochemistry of m-OMe-pBA



Scheme 56

In an NMR tube, a solution of **m-OMe-pBA** in benzene-d_6 was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). The reaction was monitored by ^{1}H NMR. After 45 minutes, ^{1}H NMR showed the formation of new peaks that correspond to three products: 4-acetyl-2-methoxy-11-oxa-tricyclo[6.3.0.0^{1,6}]undeca-2,4-diene (**m-OMe-CHD$_a$**), 4-acetyl-2-methoxy-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-OMe-ACB$_a$**) and 4-acetyl-6-methoxy-11-oxatricyclo[6.3.0.0^{1,4}]-

undeca-2,5-diene (**m-OMe-ACB$_S$**) in a ratio of 1.5 : 4.3 : 1.0 respectively . After 3.5 hours (~100% conversion), only **m-OMe-ACB$_a$** and **m-OMe-ACB$_S$** were present in a ratio of 5.7 : 1.0 respectively.

Generally, product identification depended on ^{1}H NMR spectra, especially in the olefinic region. Cycloadduct **m-OMe-CHD$_a$** (chloroform-*d*) has two olefinic protons: a doublet (J = 0.83 Hz) at 5.75 ppm (H_3) and a doublet of doublets (J = 5.76, 0.83 Hz) at 6.44 ppm (H_5). Cycloadduct **m-OMe-ACB$_a$** was identified from its partial spectrum in benzene-d_6. It shows three olefinic protons: a singlet at 4.65 ppm (H_3), a doublet of doublet of doublets (J = 9.95, 6.8, 1.83 Hz) at 5.75 ppm (H_5) and a doublet of doublets (J = 9.9, 2.98 Hz) at 6.15 ppm (H_6). **m-OMe-ACB$_S$** has three olefinic protons; a doublet at 4.65 ppm (H_5), a doublet (J = 2.85 Hz) at 5.96 ppm (H_3) and a doublet of doublets (J = 2.85, 0.53 Hz) at 6.05 ppm (H_2).

Irradiation was repeated at 313 nm. After 80 minutes, ^{1}H NMR showed the formation of **m-OMe-CHD$_a$** as the only product. Irradiation was continued for 12 hours. ^{1}H NMR showed the formation of peaks corresponding to **m-OMe-ACB$_a$, m-OMe-ACB$_S$, m-OMe-CHD$_a$** (5 : 1 : 1) beside singlets at 4.62, 4.94, 5.44, a multiplet at 5.5 and a multiplet at 6.08 ppm. The solution was left at room temperature for 20 hours and then heated at 100°C for 90 minutes. ^{1}H NMR showed the **m-OMe-CHD$_a$** concentration had increased at the expense of **m-OMe-ACB$_a$** and the three singlets at 4.62, 4.94 and 5.44 ppm. A new compound was also observed and was identified as 4-acetyl-2-methoxy-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-OMe-LCB$_{a,anti}$**). The identification was based on comparing the ^{1}H NMR spectrum of **m-OMe-LCB$_a$** with those of 4-acetyl-2-*t*-butyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-^{t}Bu-LCB$_{a,anti}$**) and 4-acetyl-2-mercaptomethyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene

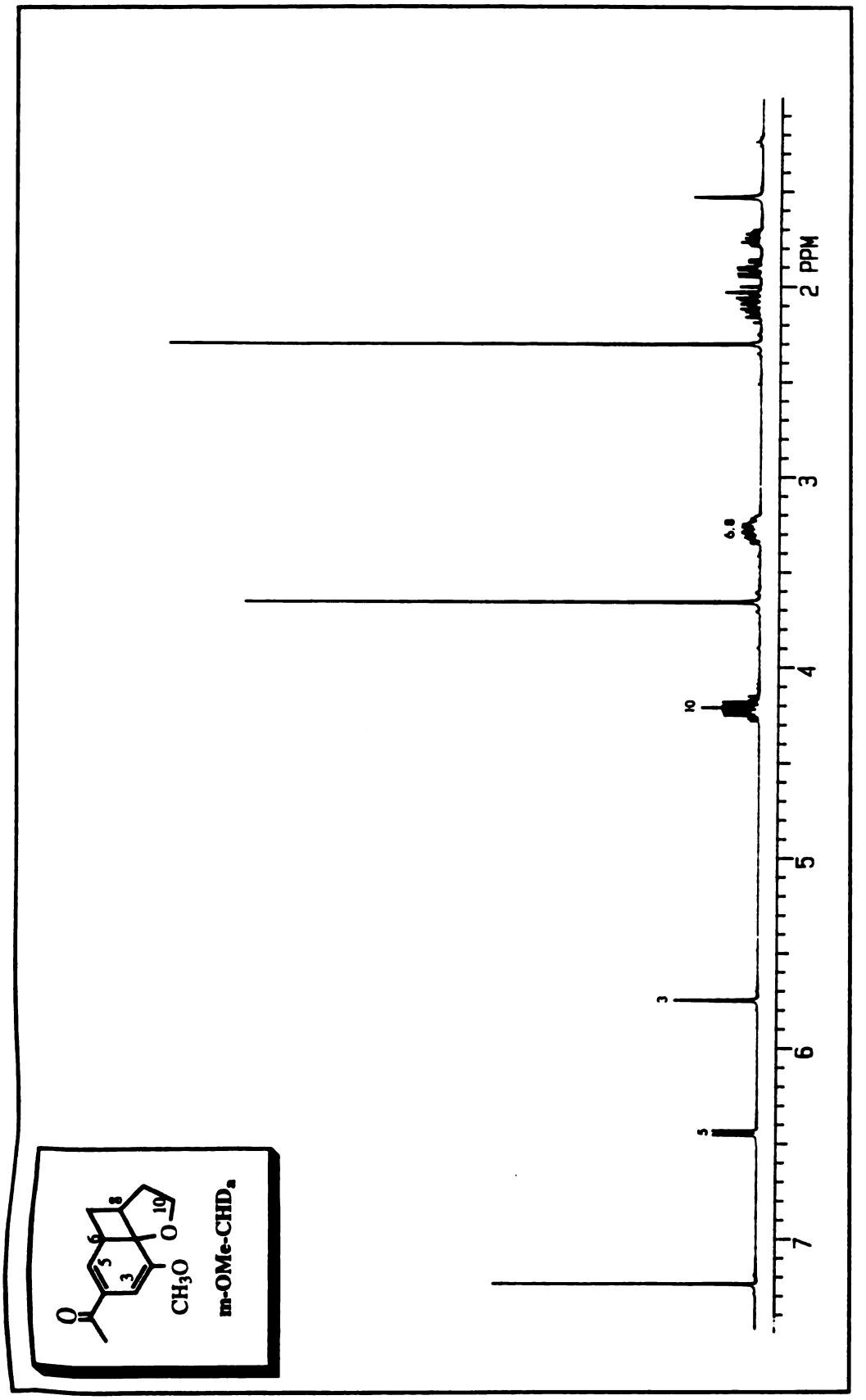


Figure 3: ^{1}H NMR spectrum of **m-OMe-CHD$_a$** in chloroform-*d*

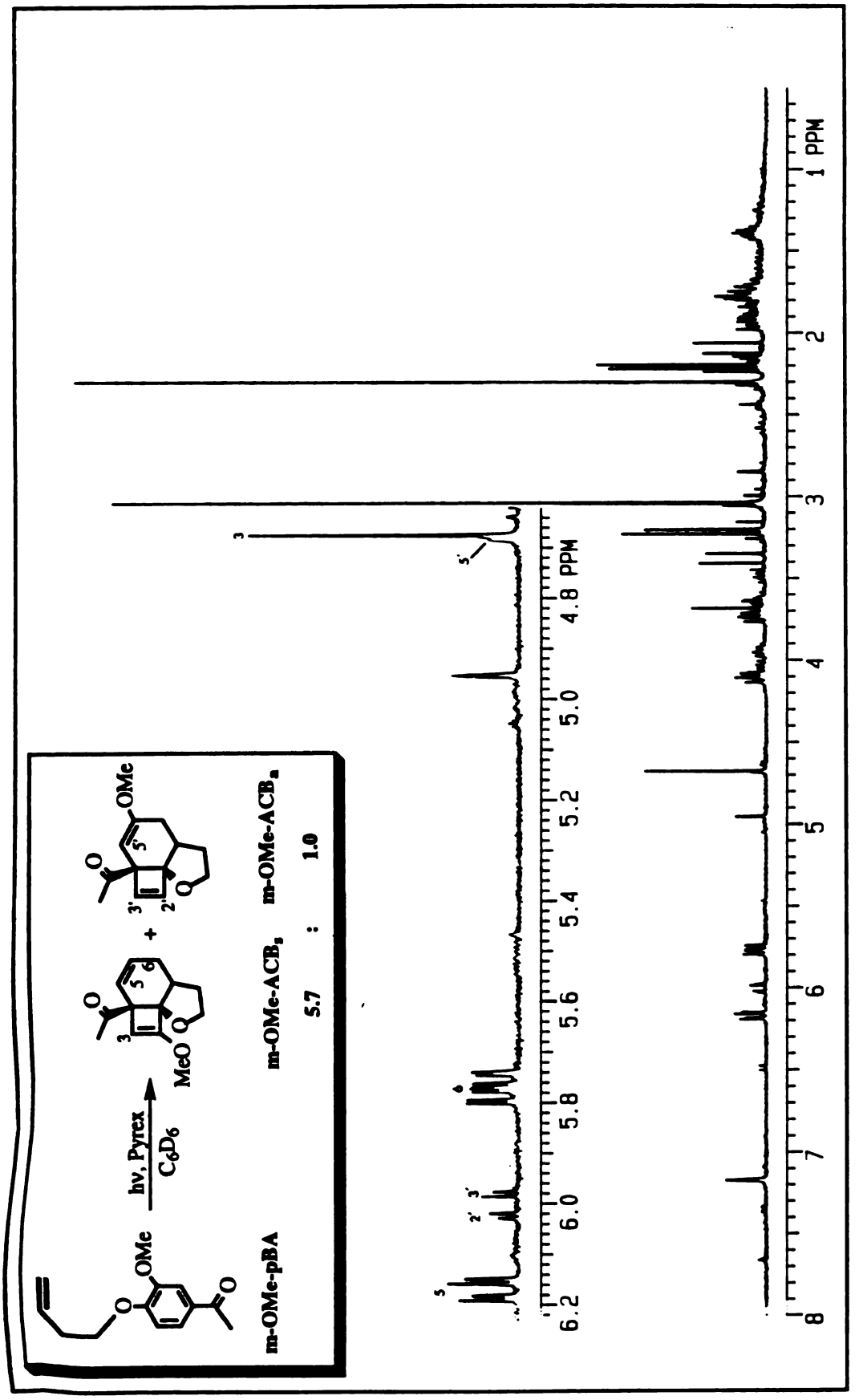


Figure 4: ^{1}H NMR spectrum of a mixture of **m-OMe-ACB$_a$** and **m-OMe-ACB$_s$** obtained by irradiation of **m-OMe-pBA** in benzene-d_6 using Pyrex-filtered light.

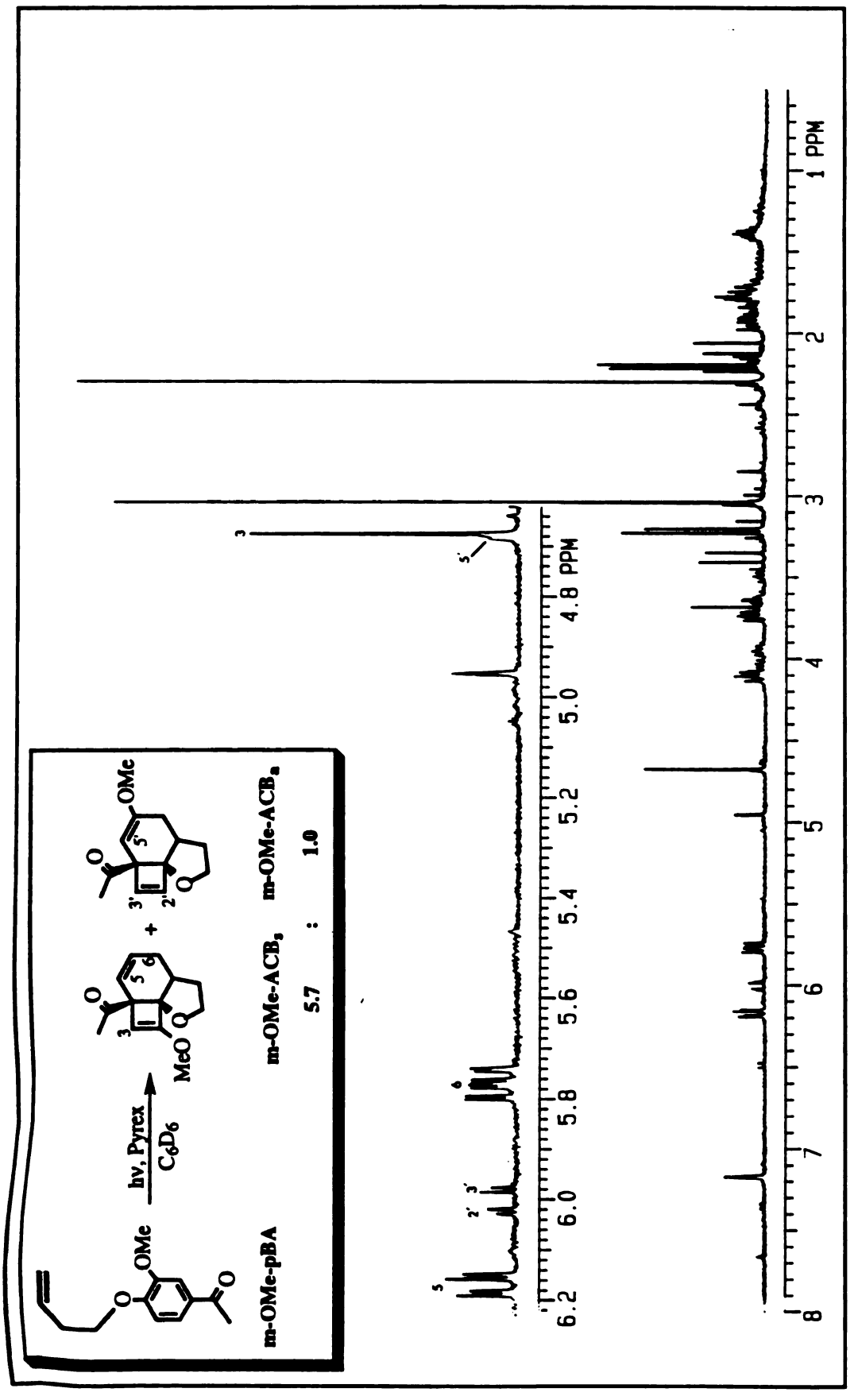
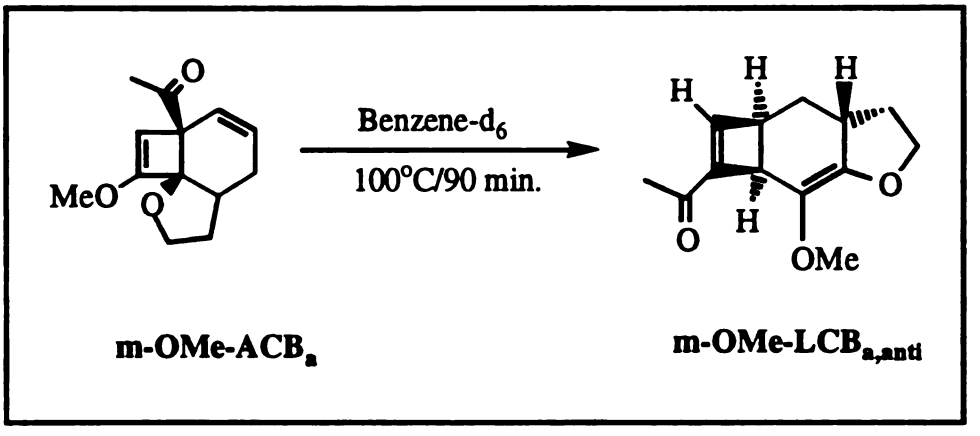


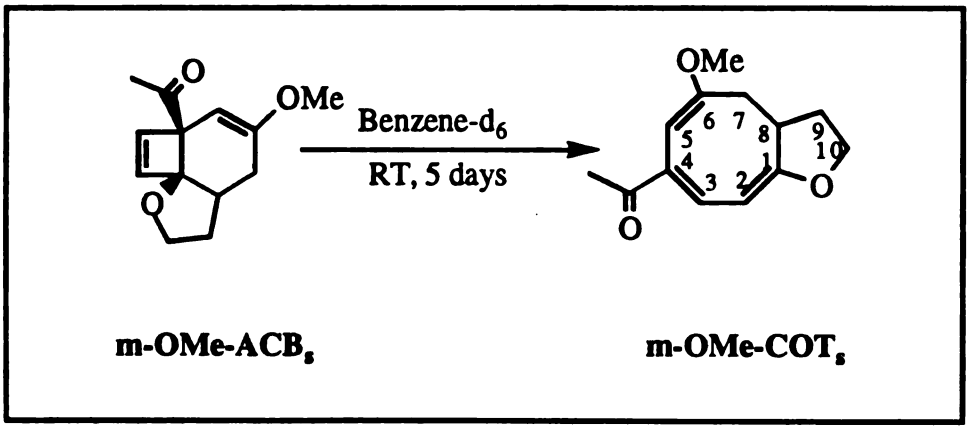
Figure 4: ^{1}H NMR spectrum of a mixture of **m-OMe-ACB$_a$** and **m-OMe-ACB$_s$** obtained by irradiation of **m-OMe-pBA** in benzene-d_6 using Pyrex-filtered light.

(**mSMe-LCB$_{a,anti}$**). The high similarity between their spectra suggested that **m-OMe-LCB$_{a,anti}$** has the same stereochemistry as **m-^{t}Bu-LCB$_{a,anti}$** and **m-SMe-LCB$_{a,anti}$** (the bridgehead proton, H_8, is syn to the cyclobutene ring and anti to H_3).(cf. Table 7).



Scheme 57

In an NMR tube the ketone was dissolved in benzene-d_6 and irradiated using uranium-filtered light ($\lambda \geq 334$ nm). After 43 hours of irradiation (> 80% conversion), ^{1}H NMR showed the presence of **m-OMe-ACB$_a$** and **m-OMe-ACB$_s$** in a ratio of 2.8 : 1.0. The solution was left at room temperature in the dark for 5 days. ^{1}H NMR showed the formation of three products; **m-OMe-CHD$_a$** and



Scheme 58

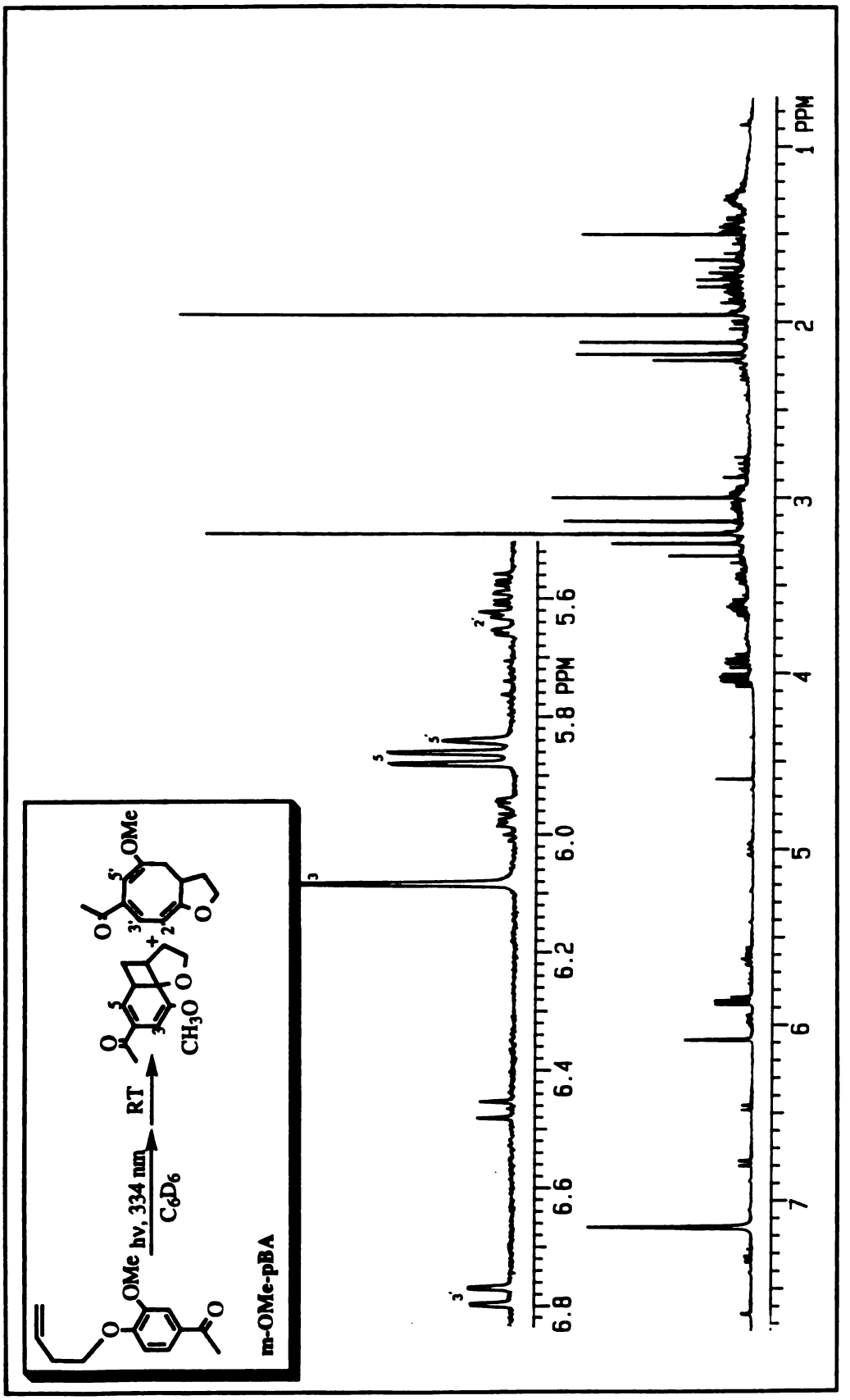
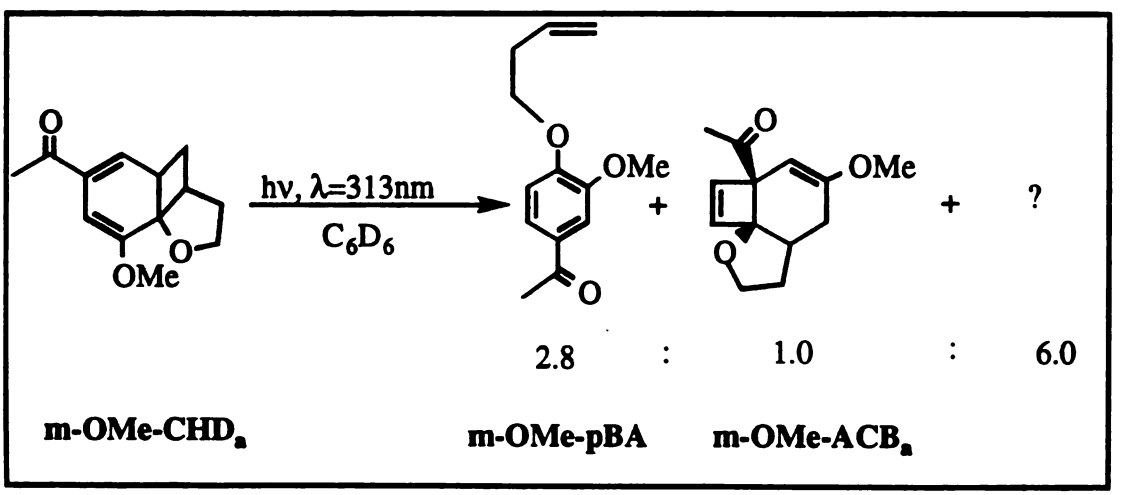


Figure 5: ^{1}H NMR spectrum of a mixture of **m-OMe-CHD$_a$** and **m-OMe-COT$_a$** obtained by irradiation of **m-OMe-pBA** in benzene-d_6 and leaving the sample at room temperature.

m-OMe-COT$_S$ in a ratio of 2.5 : 1.0 and an unidentified product. **m-OMe-COT$_S$** was identified from its partial ^{1}H NMR spectrum (olefinic protons region): δ 5.54 (dd, J = 8.5, 2.4 Hz, 1H) 5.86 (broad singlet, 1H) and 6.78 (dd, J = 8.5, 0.90 Hz). The ^{1}H NMR partial spectrum for **m-CN-COT$_S$** in benzene-d_6 is as follows: δ 5.28 ppm (dd, J = 8.23, 1.75 Hz, 1H) 6.69 (d, J = 8.23 Hz, 1H) and 7.2 (broad singlet, 1H). The only difference between the spectra is the chemical shift of H_5 which is due to the difference between the electronic effect of the cyano and methoxy groups.

A sample of **m-OMe-pBA** in benzene-d_6 was placed in ice-water bath and irradiated using Pyrex-filtered light. After 1 hour, ^{1}H NMR showed the presence of starting material (45%), **m-OMe-CHD$_a$** (2.1%), **m-OMe-ACB$_a$** (7.1%) and **m-OMe-ACB$_S$** (1.7%). After 4 hours the percentages became 2.3%, 2.0%, 18.5% and 4.4%.

The previous experiment was repeated at 55°C. After 40 minutes, ^{1}H NMR showed the presence of starting material (69.4%), **m-OMe-CHD$_a$** (2.9%), **m-OMe-ACB$_a$** (16.1%)and **m-OMe-ACB$_S$** (4.4%). After 4 hours the percentages became 0.0%, 0.0%, 44% and 4.6%.



Scheme 59

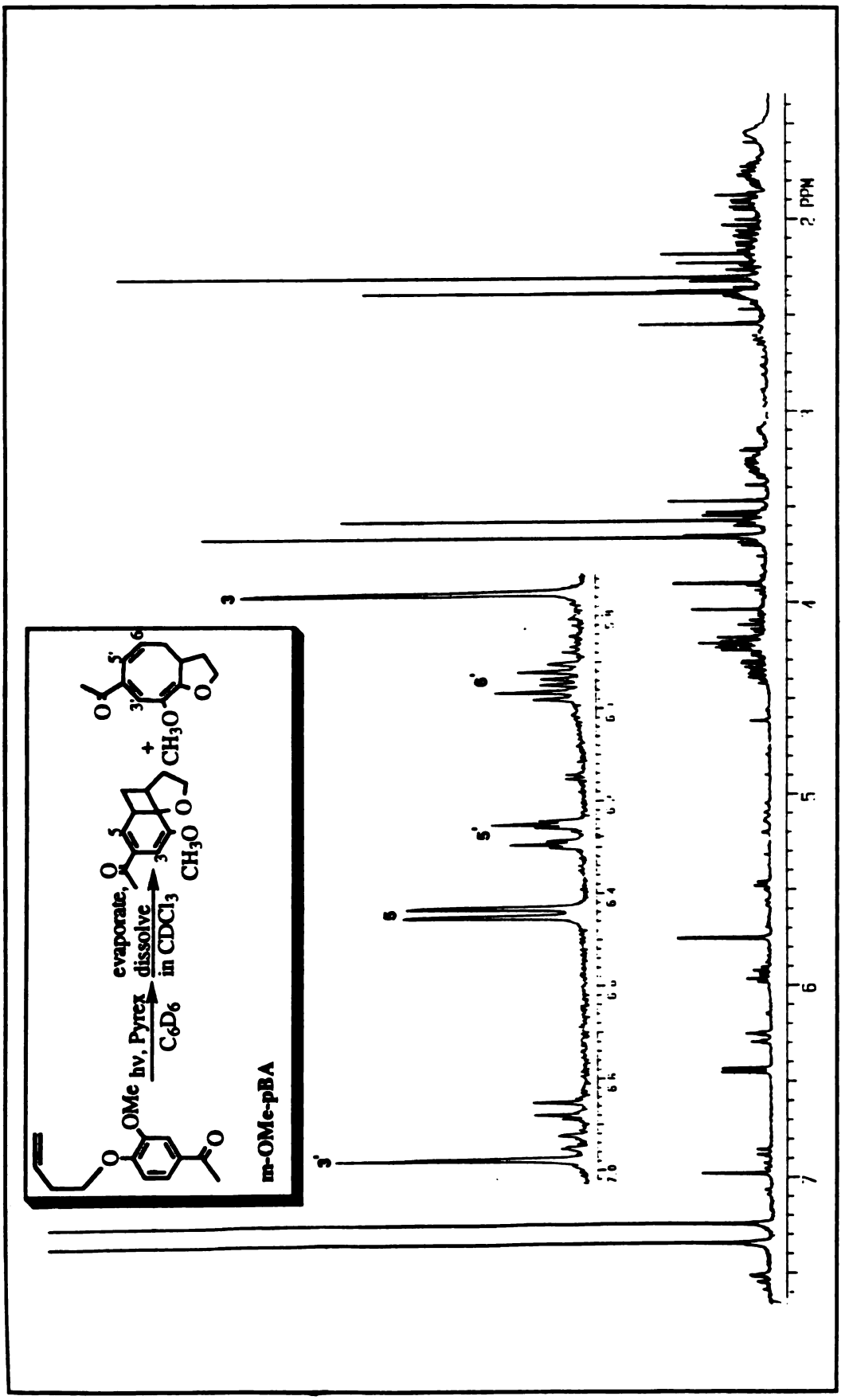
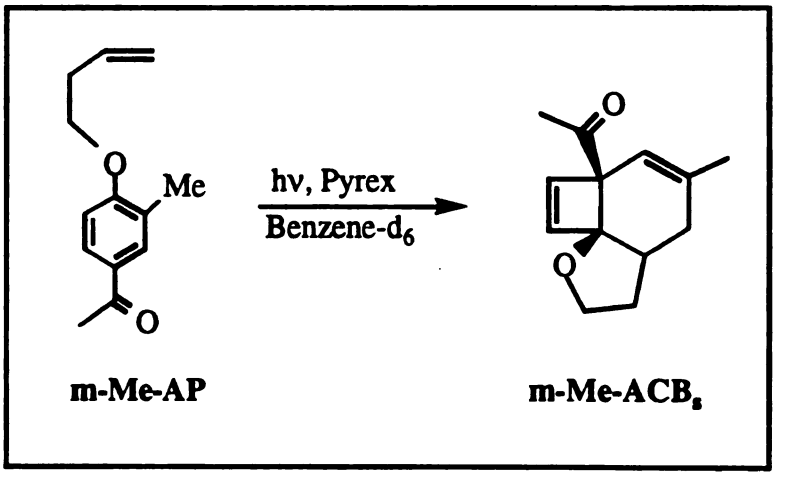


Figure 6: ^{1}H NMR spectrum of a mixture of **m-OMe-CHD$_a$** and **m-OMe-COT$_a$** in chloroform-*d* obtained by irradiation of **m-OMe-pBA** in benzene.

In an NMR tube a solution of **m-OMe-CHD$_a$** in C_6D_6 was irradiated at 313 nm. After 40 minutes (12% conversion), ^{1}H NMR showed the formation of **m-OMe-pBA** and **m-OMe-ACB$_a$** in a ratio of 2.8 :1.0 and an unidentified product. This ratio remained the same at up to 72% conversion.

Preparative scale photolysis (1.0 gm of the ketone in 500 ml dry benzene) was carried out. After solvent was evaporated, ^{1}H NMR of the residue ($CDCl_3$) showed the presence of three compounds; **m-OMe-pBA, m-OMe-CHD$_a$** and 4-acetyl-2-methoxy-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-OMe-COT$_a$**) in a ratio of 1.0 : 5.5 : 3.5. When the sample was left overnight, ^{1}H NMR showed that **m-OMe-COT$_a$** totally disappeared while the concentration of **m-OMe-CHD$_a$** increased. The mixture was purified by column chromatography (silica gel, 20% ethyl acetate/hexanes) to give 0.11 gm of starting material and 0.37 gm of 4-acetyl-2-methoxy-11-oxa-tricyclo[6.3.0.0^{1,6}]undeca-2,4-diene (**m-OMe-CHD$_a$**). **m-OMe-COT$_a$** was identified from its partial NMR spectrum. It has three olefinic protons: doublet of triplets (J = 13.13, 5.96 Hz) at 5.94 ppm (H_6), a doublet of triplets (J = 13.19, 2.19 Hz) at 6.28 ppm (H_5) and a broad singlet at 6.98 ppm (H_3).

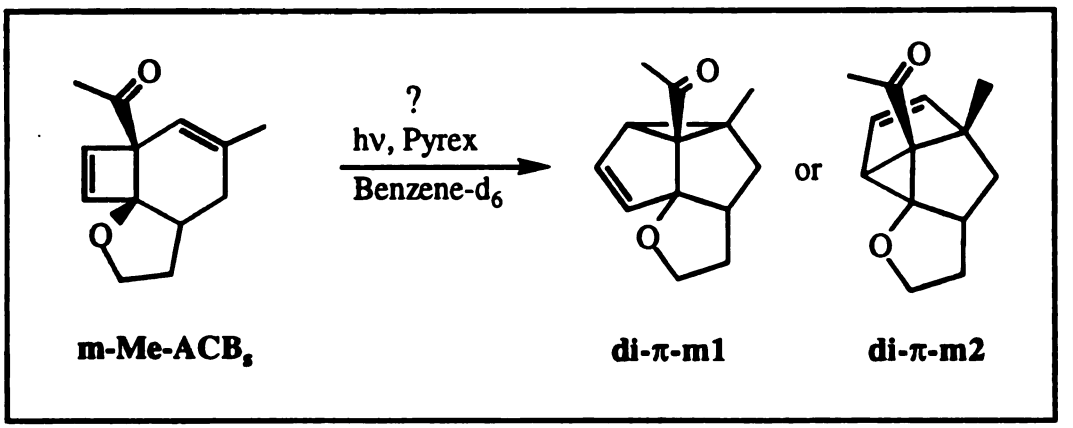
Photochemistry of m-Me-pBA



m-Me-AP **m-Me-ACB$_s$**

Scheme 60

A solution of **m-Me-pBA** in benzene-d_6 was degassed and irradiated using Pyrex-filtered light. After 2 hours irradiation, ^{1}H NMR showed that 4-acetyl-6-methyl-11-oxatricyclo-6.3.0.0^{1,4}]undeca-2,10-diene (**m-Me-ACB$_S$**) was the only product. ^{1}H NMR spectrum of this compound showed three olefinic protons; a broad singlet at 5.5 ppm (H_5), a doublet (J = 2.88 Hz) at 5.91 ppm (H_3) and a doublet of doublets (J = 2.8, 0.5 Hz) at 6.07 ppm (H_2).



Scheme 61

When the solution was further irradiated, new peaks started to appear [δ 5.35 (dd, J = 5.6, 2.5 Hz); 5.13 (dd, J = 5.6, 0.8 Hz) and 3.05 (dd, J = 2.5, 0.8 Hz)]. Structure assignment depended upon this partial spectrum. The 5.5 Hz coupling constant is characteristic of cyclopentene olefinic protons.[87,88] This suggested that a cyclopentene ring is present, also from comparing the partial ^{1}H NMR spectrum of this compound (C_6D_6) with that of compounds **1** ($CDCl_3$) [δ 5.5 (d, J = 5.6 Hz, 1H) 5.68 (dd, J = 5.6, 2.2 Hz, 1H)] and **2** ($CDCl_3$) [δ 2.55 (d, J = 2.3 Hz, 1H) 5.41 (dd, J = 5.3, 2.3 Hz, 1H) 5.69 (dd, J = 5.3, 2.3 Hz, 1H)],[91] its structure was proposed to be either tetracyclic compound **di-π–m1** which may be due to the di-π–methane photoreaction of **m-Me-ACB$_S$** or its vinyl cyclopropane rearrangement product, **di-π–m2**.

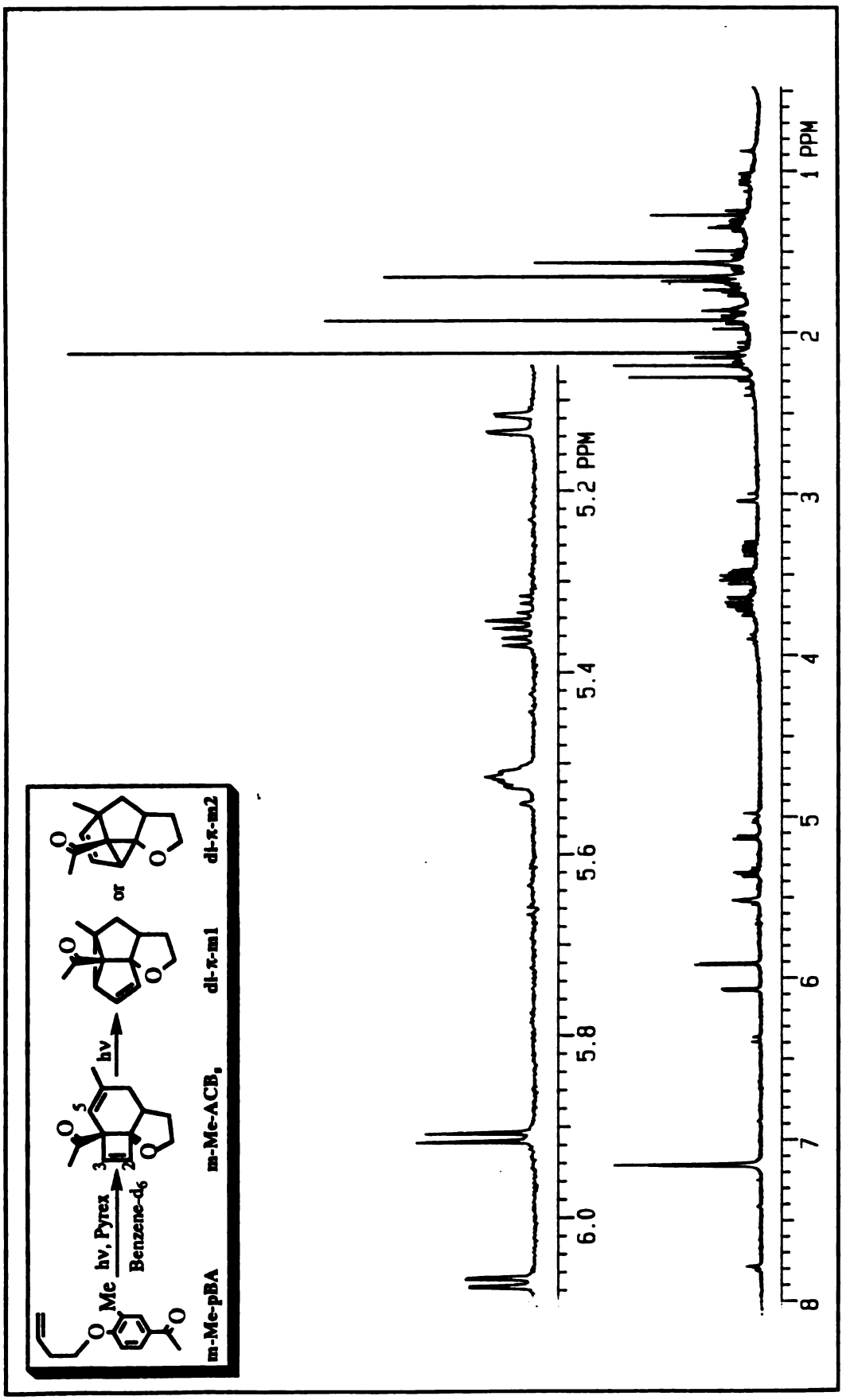


Figure 7: ^{1}H NMR spectrum of a mixture of **m-Me-ACB$_s$** and its photorearrngement product after irradiation in benzene-d_6 using Pyrex-filtered light.

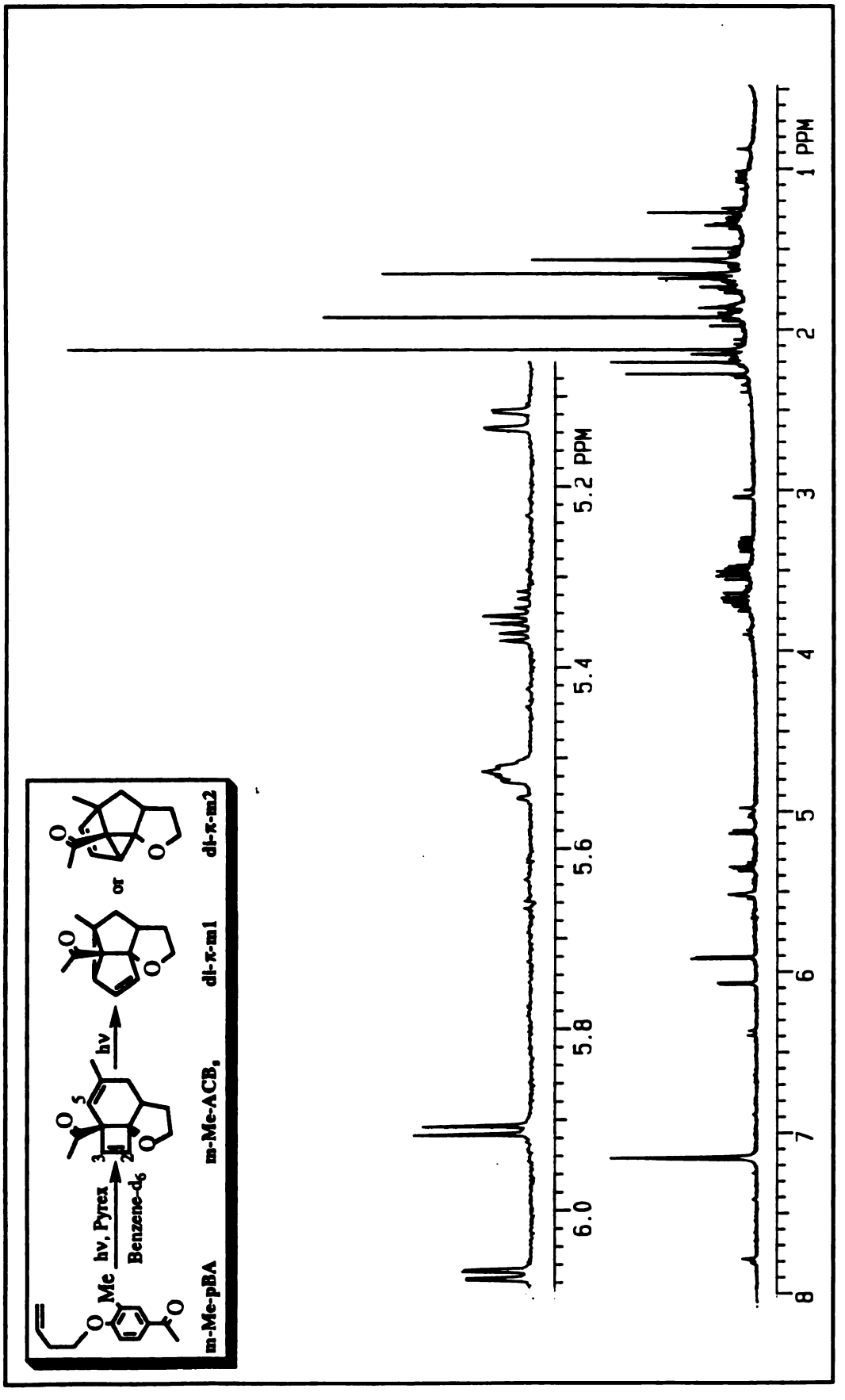
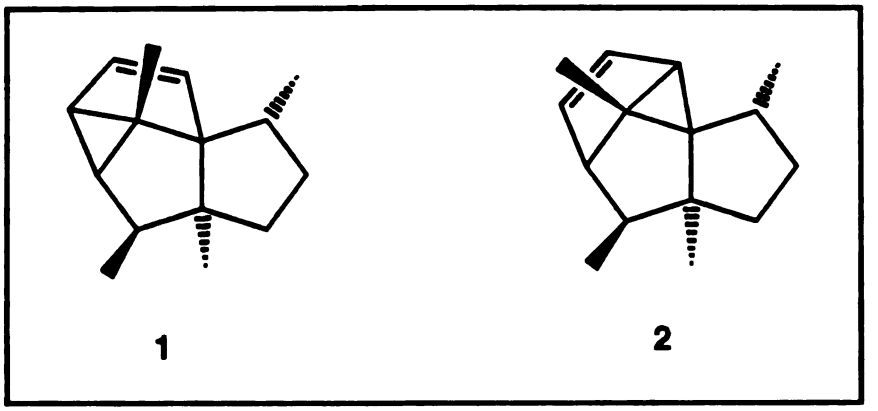


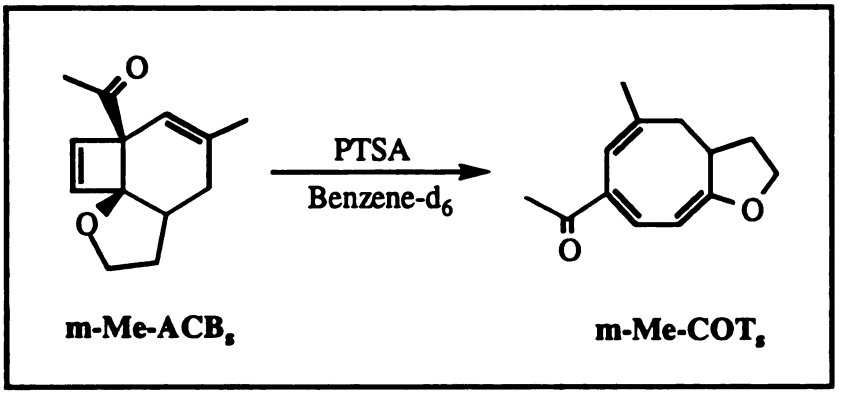
Figure 7: ^{1}H NMR spectrum of a mixture of **m-Me-ACB$_2$** and its photorearrngement product after irradiation in benzene-d_6 using Pyrex-filtered light.



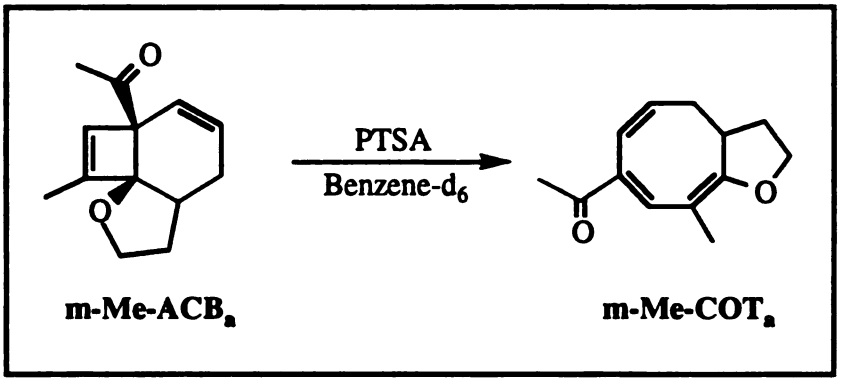
Scheme 62

In order to prevent the occurrence of the secondary photoreaction, irradiation of **m-Me-pBA** was performed again using uranium filter which permits only light of wavelengths longer than 334 nm at which the carbonyl group of **m-Me-ACB$_S$** does not absorb. The NMR tube was taped to the immersion well and hence the solution temperature was slightly higher than room temperature. The reaction was slower due to lower light intensity. After 105 hours of irradiation, only two compounds were observed by ^{1}H NMR spectroscopy; **m-Me-ACB$_S$** which arises from the addition of the double bond towards the benzene ring, and its regioisomer 4-acetyl-2-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-Me-ACB$_a$**). The product ratio was ~ 8 : 1 and chemical yields was 60% and 7.5% with respect to **m-Me-pBA** consumed. When the NMR tube was placed about one inch away from the immersion well and irradiation was repeated under the same conditions, **m-Me-ACB$_a$** was not observed by NMR. The structure of **m-Me-ACB$_a$** was determined using its partial ^{1}H NMR spectrum. It has three olefinic protons; a doublet of doublets of doublets (J = 9.8, 6.2, 3.5 Hz) at 5.57 ppm (H_6), a quartet (J = 1.6 Hz) at 5.64 ppm (H_2) and a doublet of doublets of doublets (J = 10.0, 2.5, 1.3 Hz) at 5.92 ppm (H_5).

m-Me-ACB$_s$ and **m-Me-ACB$_a$** were stable in C_6D_6 solution at room temperature for at least 14 days. When a crystal of *p*-toluenesulfonic acid was added to the solution, a yellow color developed within seconds. ^{1}H NMR analysis showed the disappearance of the peaks corresponding to the cyclo-



Scheme 63



Scheme 64

butenes along with the appearance of new peaks corresponding to 4-acetyl-6-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Me-COT$_s$**) and 4-acetyl-2-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Me-COT$_a$**). ^{1}H NMR showed that **m-Me-COT$_s$** has three olefinic protons; a doublet of doublets (J = 8.2, 1.9 Hz) at 5.58 ppm (H_2), a broad singlet at 6.54 ppm (H_5) and a doublet (J = 8.2 Hz)

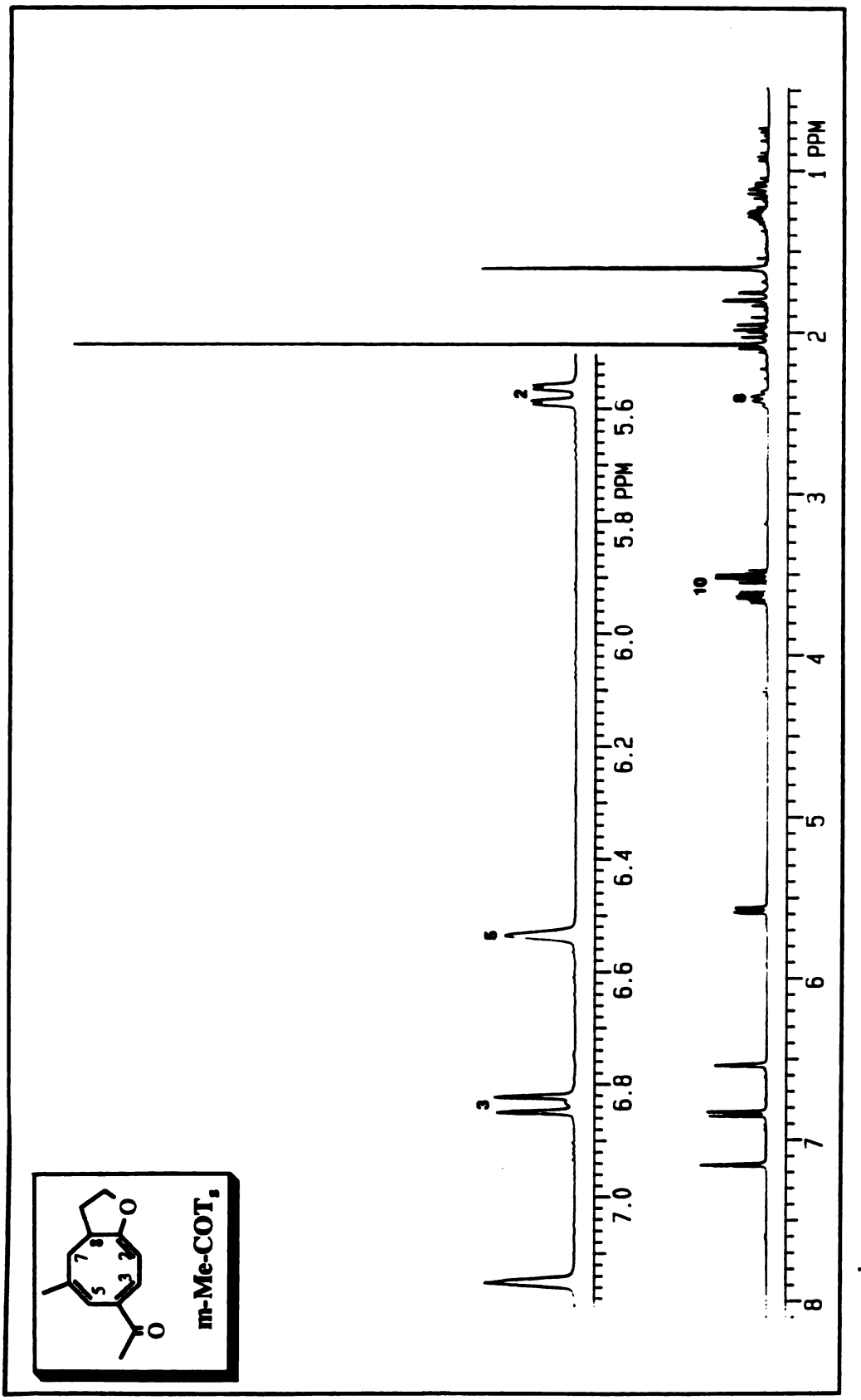
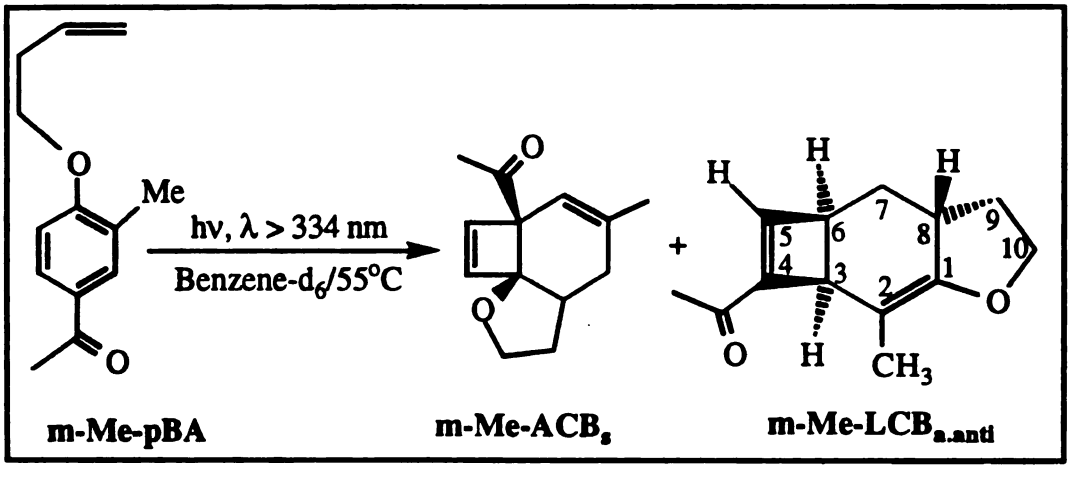


Figure 8: ^{1}H NMR spectrum of **m-Me-COT$_s$** in benzene-d_6.

at 6.84 ppm (H_3). **m-Me-COT$_a$** also has three olefinic protons, a doublet of triplets (J = 12.6, 4.39 Hz) at 5.65 ppm (H_6), a doublet of triplets (J = 12.6, 2.32 Hz) at 6.58 ppm (H_5) and a singlet at 6.83 ppm.

m-Me-pBA was irradiated in benzene-d_6 at 55°C using Pyrex-filtered light ($\lambda \geq 290$ nm). After 40 minutes, ^{1}H NMR showed the presence of starting material (65%), **m-MeACB$_s$** (7.3%) and 4-acetyl-2-methyl-11-oxatricyclo[6.3.0.0^{3,6}]-undeca-1,4 diene (**m-Me-LCB$_{a,anti}$**) (14.2%). After 4 hours the percentages became 27.5%, 10.0% and 13.6% respectively. The ^{1}H NMR spectrum of **m-Me-LCB$_{a,anti}$** showed the presence of only one olefinic proton, which appeared as a doublet at 6.04 ppm (J = 1.3 Hz, H5) coupled to a ddt at 2.66 ppm (bridgehead proton, H_6). The methyl group appeared as a doublet at 2.27 ppm. The relatively large chemical shift of the methyl group is due to its being allylic. It couples to H_8 with a homoallylic coupling constant of 2.27 Hz. Comparing the ^{1}H NMR spectra of **m-Me-LCB$_{a,anti}$** with those of **m-SMe-LCB$_{a,anti}$** and **m-^{t}Bu-LCB$_{a,anti}$** showed great similarities between chemical shifts and coupling constants (cf. table 7). This suggested that they have the same stereochemistry specifically that **m-Me-LCB$_{a,anti}$** has H_8 syn to the cyclobutene ring.



Scheme 65

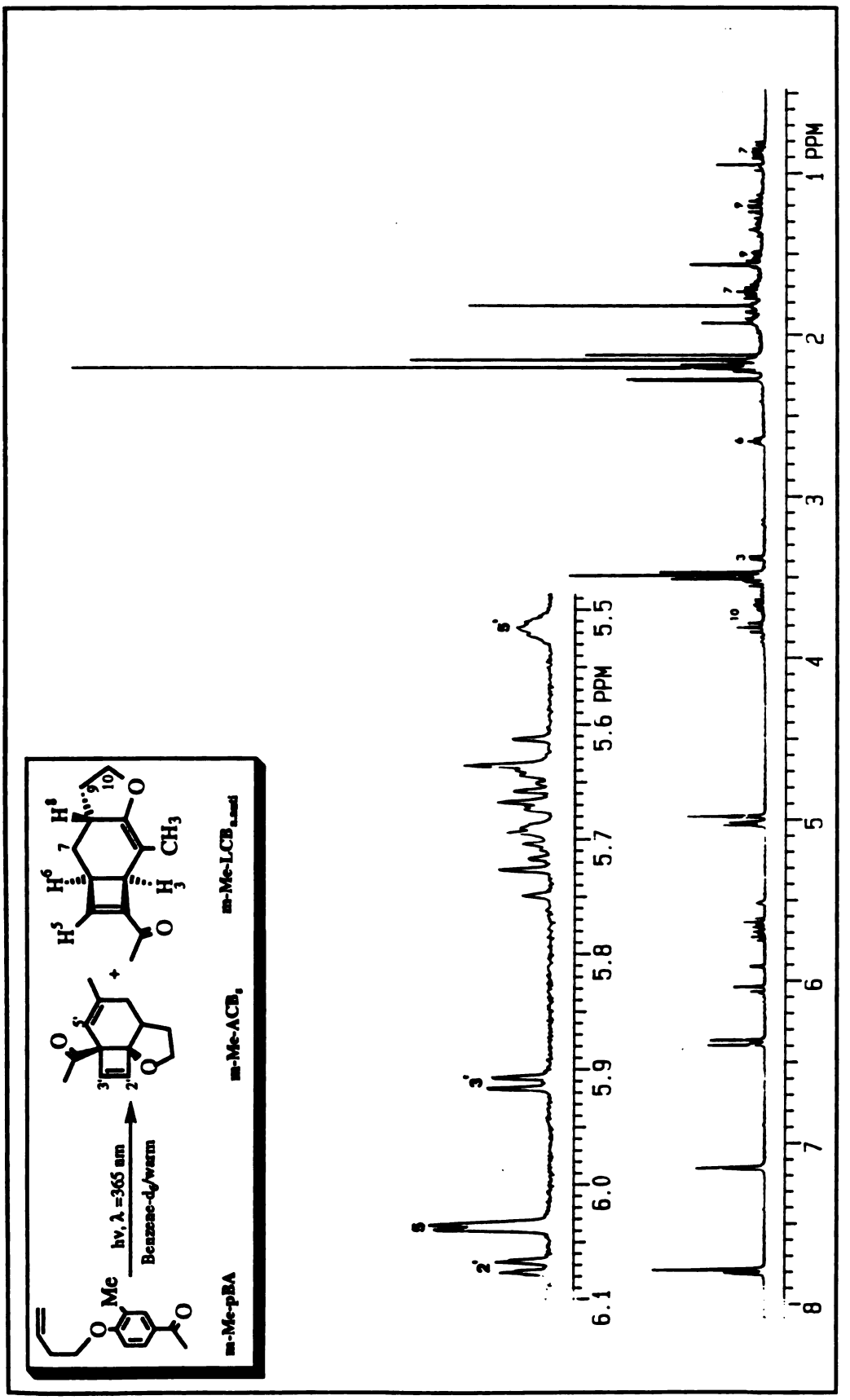
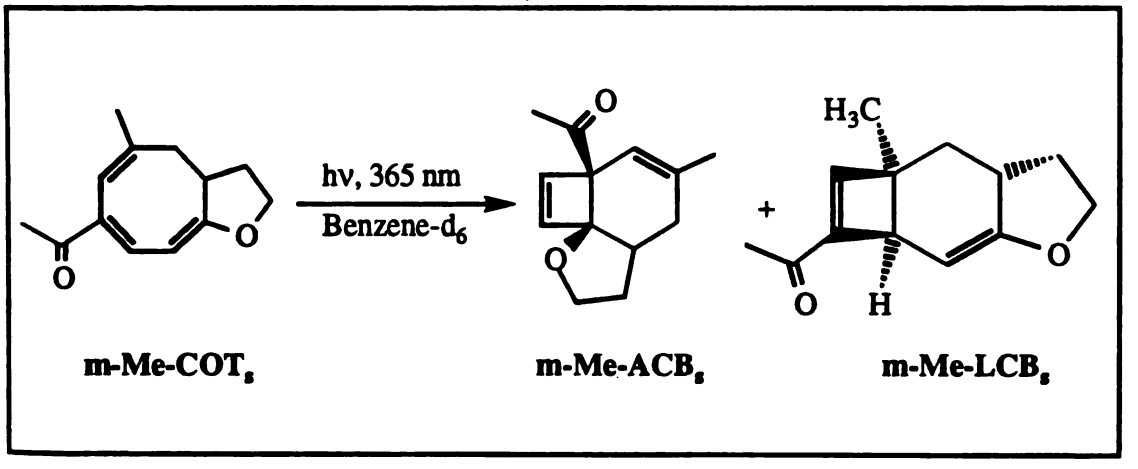


Figure 9: ^{1}H NMR spectrum of a mixture of **m-Me-ACB$_1$** and **m-Me-LCB$_{1,anti}$** obtained by irradiation of **m-Me-pBA** in warm benzene-d_6 at 365 nm.

m-Me-pBA was also irradiated at 365 nm in C_6D_6. The solution became warm during the irradiation because of the lamp. ^1H NMR showed that two products were formed; **m-Me-ACB$_s$** and **m-Me-LCB$_{a,anti}$** in a ratio of 1 : 2. When this experiment was repeated, ^1H NMR showed the formation of three products; **m-Me-ACB$_s$**, **m-Me-ACB$_a$** and **m-Me-LCB$_{a,anti}$** in a ratio of 2.1 : 3.3 : 1.

Irradiation was also performed at low temperature. In an NMR tube, a solution of **m-Me-pBA** in benzene-d_6 was placed in an ice-water bath and irradiated using Pyrex-filtered light. After 1 hour, ^1H NMR showed the presence of starting material (84.8%) and **m-Me-ACB$_s$** (5.4%). After 4 hours the percentages became 55.2% and 13.1%, whereas after 9 hours it became 35.5% and 17.1%, respectively.

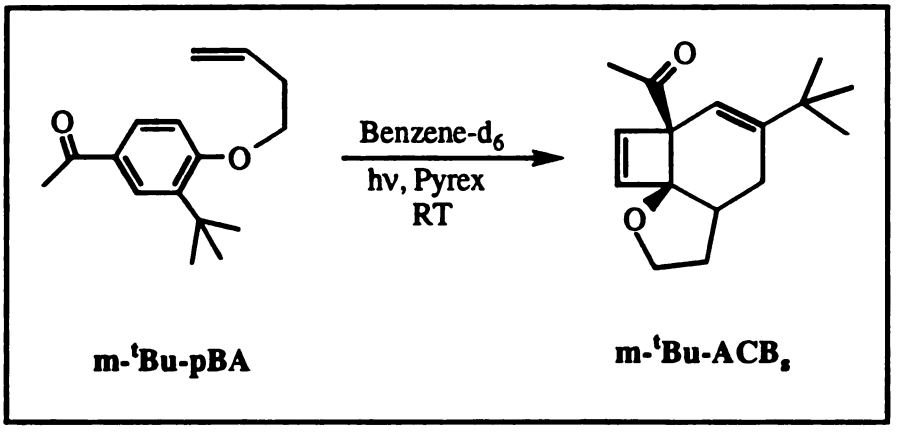
Large scale irradiation of 1.0 gm of **m-Me-pBA** in 500 ml of dry benzene using Pyrex filtered light led to the formation of only 0.1 gm of **m-Me-COT$_s$** after isolation using column chromatography.



Scheme 66

Irradiation of isolated **m-Me-COT$_S$** at 365 nm in C_6D_6 for 4 hours at room temperature led to the formation of **m-Me-ACB$_S$** as the major product in addition to a minor product. The partial NMR spectrum of the minor product showed a broad doublet at 3.05 ppm (J = 6.32 Hz), a singlet at 6.14 ppm and a doublet of doublets at 5.3 ppm (J = 6.35, 2.5 Hz). This suggested that this compound was 4-acetyl-6-methyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4 diene (**m-Me-LCB$_{S,anti}$**). The ratio of the two compounds was 3.6 : 1.0

Photochemistry of m-^{t}Bu-pBA

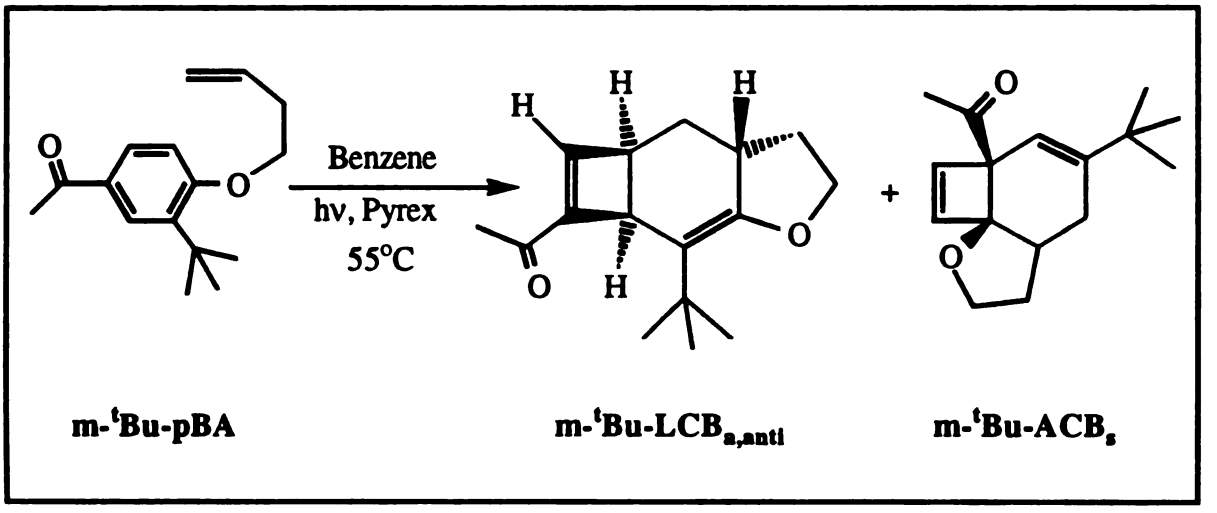


Scheme 67

In an NMR tube, a solution of **m-^{t}Bu-pBA** in benzene-d_6 was degassed and irradiated using Pyrex-filtered light. After 40 minutes irradiation (~7% conversion) new sets of olefinic peaks were detected by ^{1}H NMR: 5.88 ppm, (d, J = 2.85 Hz), 6.10 ppm (dd, J = 2.75, 0.55 Hz) and 5.68 ppm (d, J = 2.35 Hz) . Product yield was found to be 70% (with respect to reacted starting material). Starting material totally disappeared after 20 hours irradiation . The product yield dropped from 70% to 10%. Based on the partial ^{1}H NMR spectrum the

photoproduct was proposed to be 4-acetyl-6-*t*-butyl-11-oxatricyclo[6.3.0.0^{1,4}]-undeca-2,5-diene (**m-^{t}Bu-ACB$_S$**)

m-^{t}Bu-pBA was irradiated in ice-water cooled benzene-d_6 using Pyrex-filtered light. After 1 hour, ^{1}H NMR showed the presence of starting material (94.6%) and **m-^{t}Bu-ACB$_S$** (4.9%). After 4 hours the percentages became 66.0% and 14.6% where as after 9 hours became 30% and 19.1% respectively. Placement of the NMR tube in boiling water for 40 minutes, resulted in no change to **m-^{t}Bu-ACB$_S$** by ^{1}H NMR.



Scheme 68

The previous experiment was repeated at 55°C. After 40 minutes, ^{1}H NMR showed the presence of starting material (62.4%), **m-^{t}Bu-ACB$_S$** (2.2%) and 4-acetyl-2-*t*-butyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-^{t}Bu-LCB$_{a,anti}$**) (20.1%). After 4 hours the percentages became 18.9%, 3.4%, and 27.9% respectively.

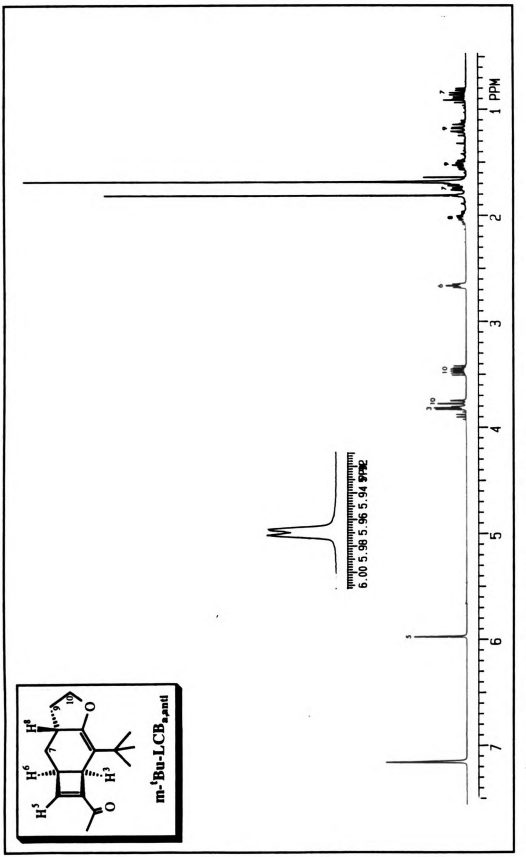
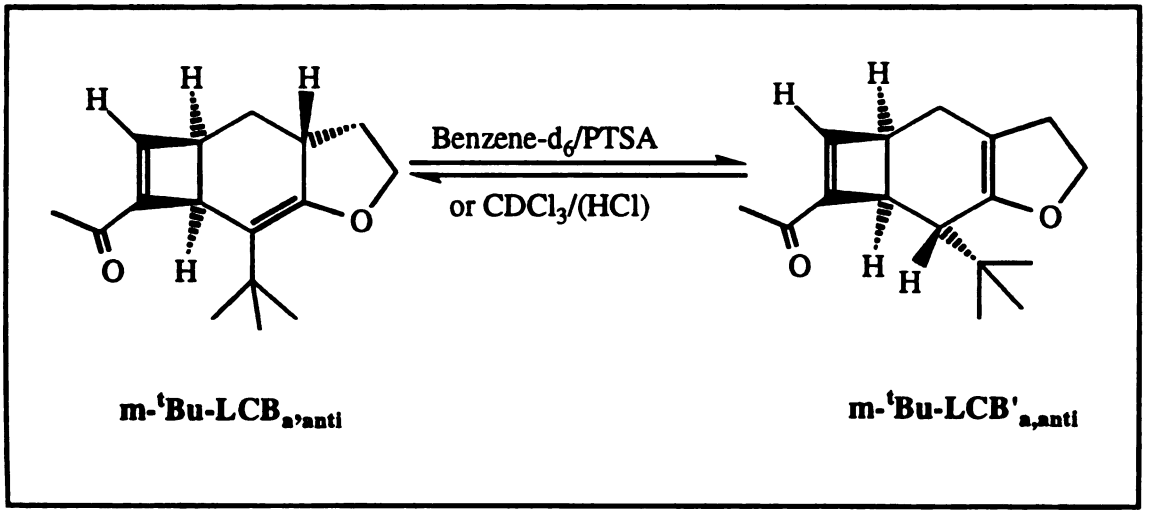


Figure 10: ^{1}H NMR spectrum of **m-^{t}Bu-LCB$_{a,anti}$** in benzene-d_6.

Large scale irradiation was performed using 0.50 gm of **m-^{t}Bu-pBA** in 150 ml dry benzene. After 12 hours irradiation using Pyrex-filtered light, it was noticed that the solution had warmed from the uv lamp (~40°C). ^{1}H NMR showed the formation of (**m-^{t}Bu-LCB$_{a,anti}$**). The photoproduct was isolated by prep TLC and identified by ^{1}H and ^{13}C-NMR analysis. ^{1}H NMR (benzene-d_6) showed the presence of only one olefinic proton at 5.97 ppm (d, J = 1.3 Hz) while ^{13}C NMR showed the presence of two double bonds. Homonuclear decoupling experiments supported the proposed structure.

The stereochemistry of **m-^{t}Bu-LCB$_{a,anti}$** was established by nOe experiments which showed that H_8 is syn to the cis-cyclobutene ring. Irradiation of H_6 led to the enhancement of H_3 (8.6%) , H_5 (7.6%) and $H_{7\alpha}$ (3.64%), while H_8 was not affected. On the other hand, when H_5 was irradiated, an enhancement of H_6(4.46%) and H_8 (2.86%) was observed.



Scheme 69

When **m-^{t}Bu-LCB$_{a,anti}$** was treated with catalytic amount of para-toluenesulfonic acid in benzene-d_6, ^{1}H NMR showed the formation of 1:1 mixture

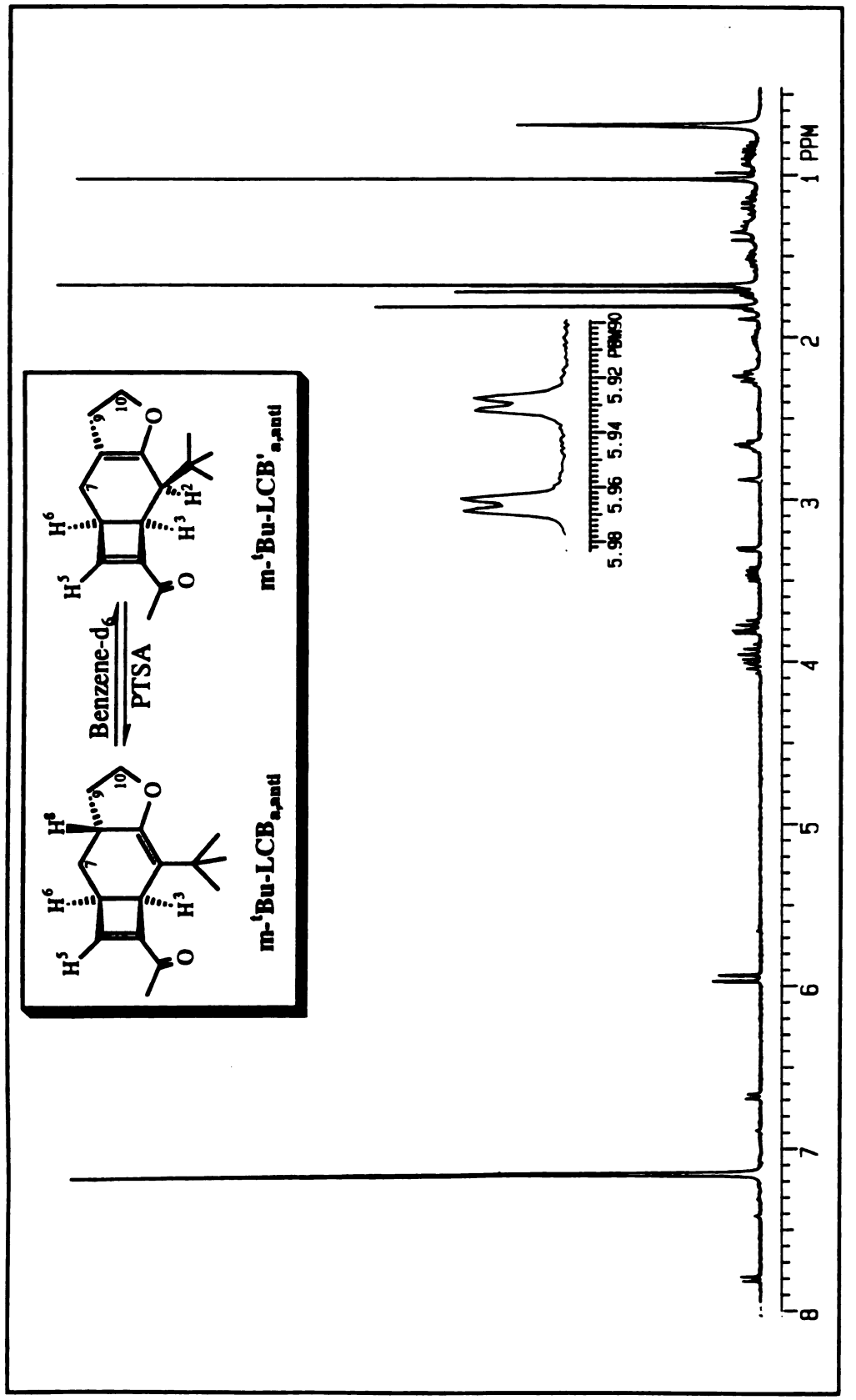
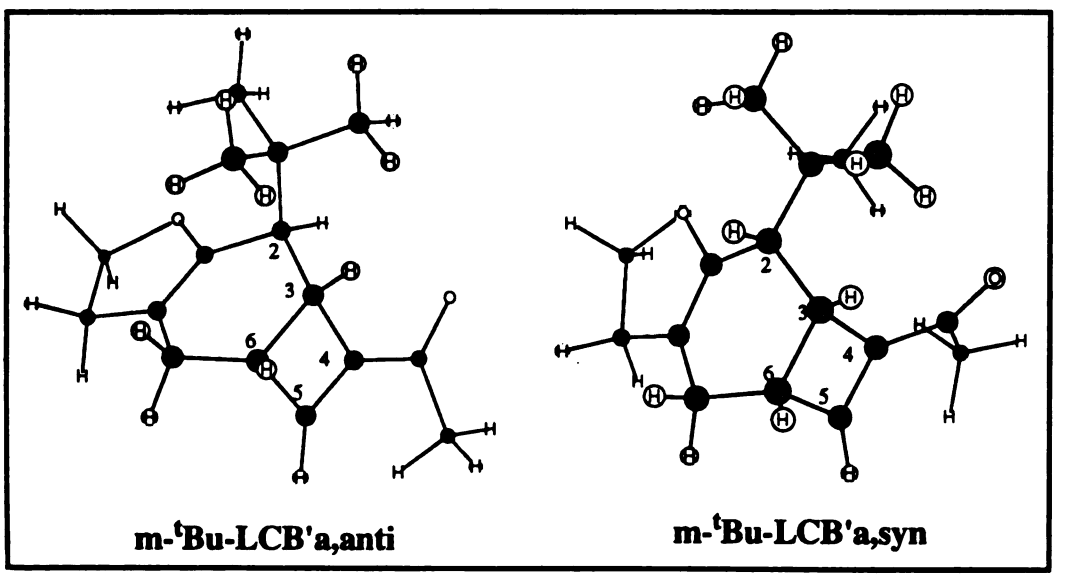


Figure 11: ^{1}H NMR spectrum of a mixture of **t-Bu-LCB'$_{a,anti}$** and **m-^{t}Bu-LCB$_{a,anti}$** obtained by treatment of **t-Bu-LCB'$_{a,anti}$** with PTSA in benzene-d_6.

of **m-^{t}Bu-LCB$_{a,anti}$** and 4-acetyl-2-*t*-butyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1$_8$,4 diene (**m-^{t}Bu-LCB'$_{a,anti}$**). The same mixture was formed when **m-^{t}Bu-LCB$_a$-anti** was dissolved in chloroform-*d* which may contain some acidic impurities. After prep TLC isolation of **m-^{t}Bu-LCB'$_{a,anti}$**, its structure was assigned using ^{1}H and ^{13}C NMR. ^{1}H NMR showed the presence of an olefinic proton at 5.94 ppm (J = 1.33 Hz) which is almost identical to that of **m-^{t}Bu-LCB$_{a,anti}$**. This suggested that the cyclobutene ring remained intact. However the chemical shifts of all the methylene protons moved to a lower field compared to those of **m-^{t}Bu-LCB$_{a,anti}$** (1.9-2.7 ppm instead of 0.85-1.74 ppm). This finding agrees with the proposed structure of **m-^{t}Bu-LCB'$_{a,anti}$** which has the cyclobutene ring junction as in **m-^{t}Bu-LCB$_a$-anti**. Moving the double bond between C_1 and C_8 caused H_7 and H_9 to be allylic which accounts for the change in chemical shifts.

A sample of **m-^{t}Bu-LCB'$_{a,anti}$** in benzene-d_6 was treated with para-toluenesulfonic acid. ^{1}H NMR analysis showed the formation of the same 1:1 mixture of **m-^{t}Bu-LCB$_{a,anti}$** and **m-^{t}Bu-LCB'$_{a,anti}$**. It is noteworthy that **m-^{t}Bu-LCB$_{a,anti}$** did not lose its stereochemistry.

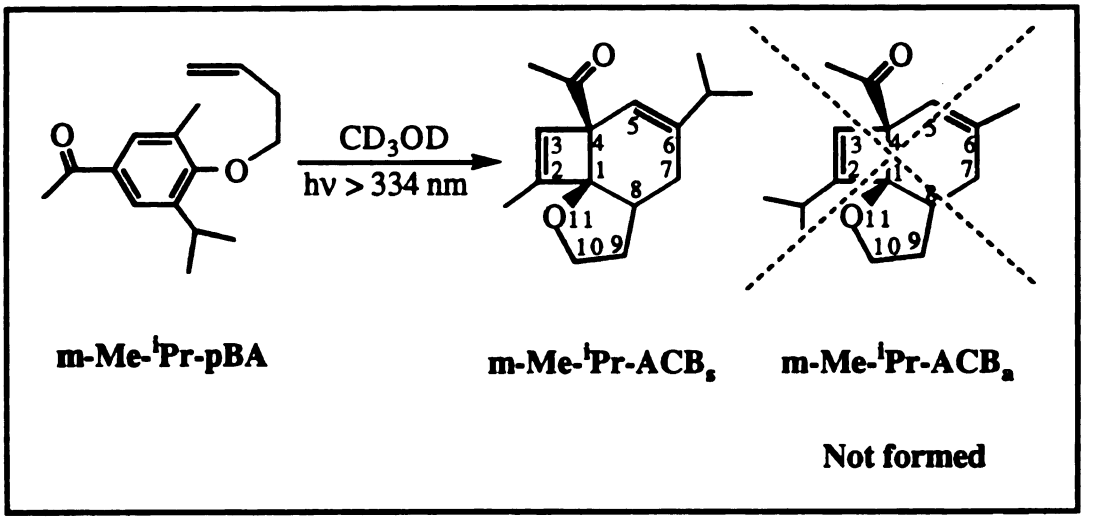


Scheme 70

m-^{t}Bu-LCB'$_{a,anti}$ has two possible stereochemical configurations; one of which has the *t*-butyl group syn to the cyclobutene ring (**m-^{t}Bu-LCB'$_{a,syn}$**) while the other has the *t*-butyl group anti to the cyclobutene ring (**m-^{t}Bu-LCB'$_{a,anti}$**). AM1 semiemperical calculations showed that the anti isomer is 4 kcal/mol more stable than the syn isomer. Also, the lowest energy geometry was calculated for both isomers and showed that the dihedral angle between H_2 and H_3 is 52° for the syn and 92° for the anti. Experimentally H_2 does not couple with H_3 which suggests that the formed product has the **anti** geometry. ^{1}H NMR nOe experiments agreed with the proposed stereochemistry. Irradiation of the bridgehead proton, H_6, induced enhancements of H_3 (2.3%). Irradiation of the olefinic proton, C_5, led to the enhancement of H_2 (2.8%). These results, again, suggested that the *t*-butyl group is anti to the cis-fused cyclobutene ring.

Large scale irradiation of **m-^{t}Bu-pBA** (0.3 gm in 150 ml dry methanol) was performed at low temperature. ^{1}H NMR analysis showed the formation of **m-^{t}Bu-ACB$_S$**. No **m-^{t}Bu-LCB$_{a,anti}$** was detected. The photoproduct was isolated by prep TLC (10% ethylacetate/hexane) as 4-acetyl-6-*t*-butyl-11- oxabicyclo[6.3.0]-undeca-1,3,5-triene (**m-^{t}Bu-COT$_S$**).

Photochemistry of m-Me-^{i}Pr-pBA

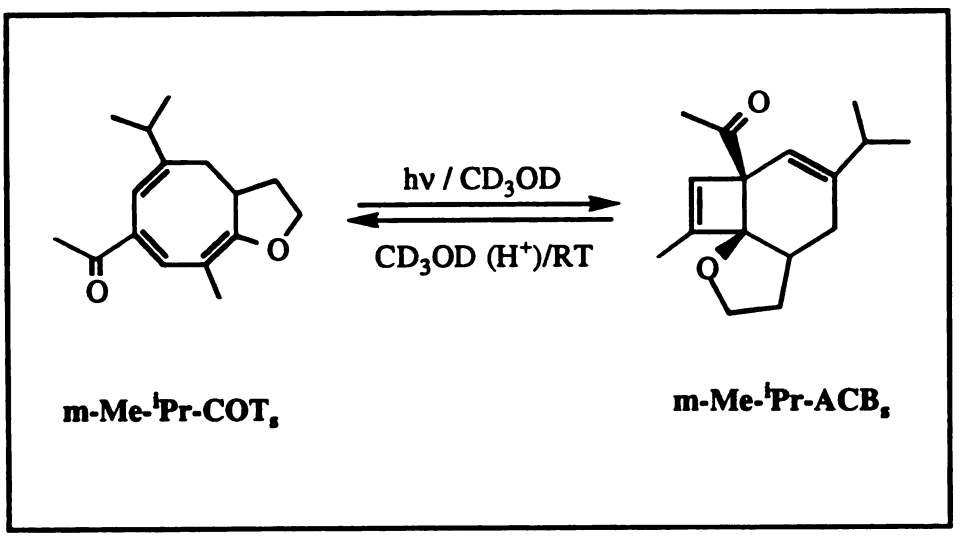


Scheme 71

In an NMR tube, a solution of **m-Me-^{i}Pr-pBA** in methanol-d4 was irradiated using uranium-glass-filtered light. After 200 hours of irradiation, ^{1}H NMR analysis showed that starting material disappeared with the formation of 4-acetyl-6-isopropyl-2-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-Me-^{i}Pr-ACB$_{s}$**) as the major product. The other regioisomer 4-acetyl-2-isopropyl-6-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-Me-^{i}Pr-ACB$_{a}$**) was not detected by ^{1}H NMR.

The structural differentiation between the two regioisomers was based on the coupling constants of the olefinic protons. For **m-Me-^{i}Pr-ACB$_{s}$**, H_3 is expected to appear as a quartet with an allylic coupling constant 1~2 Hz and H_5 a doublet of doublets with one allylic coupling constant of 2~2.5 Hz (compare to **m-^{t}Bu-ACB$_{s}$**) and another allylic coupling constant <2.0 Hz. On the other hand, for **m-Me-^{i}Pr-ACB$_{a}$**, H_3 is expected to appear as a doublet with an allylic coupling constant < 2.0 Hz and H_5 should appear as a doublet of quartets or a broad singlet (compare to **m-Me-ACB$_{s}$**). ^{1}H NMR showed the presence of two

olefinic protons; 5.42 ppm, (dd, J = 2.0, 1.1 Hz), 5.9 ppm, (q, J = 1.57 Hz). These data agree with **m-Me-^{i}Pr-ACB$_S$** as the product.



Scheme 72

m-Me-^{i}Pr-ACB$_S$ solution in methanol-d4 was left in the dark for 3 days at room temperature. The solution became yellow and ^{1}H NMR showed the formation of new peaks corresponding to 4-acetyl-6-isopropyl-2-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Me-^{i}Pr-COT$_S$**). Large scale irradiation of **m-Me-^{i}Pr-pBA** was performed using 0.4 gm of the material dissolved in 150 ml dry methanol. Irradiation was performed at < 0^{o}C and by using Pyrex-filtered light. Reaction was complete after 2 hours irradiation, after which the cyclooctatriene (**m-Me-^{i}Pr-COT$_S$**) was isolated. ^{1}H NMR showed the two olefinic protons of **m-Me-^{i}Pr-COT$_S$**; a broad singlet at 6.06 ppm (H_5) and a broad singlet at 7.04 ppm (H_3)

A solution of 6.6 mg of **m-Me-^{i}Pr-COT$_S$** was dissolved in 0.75 ml of methanol-d4 and irradiated for 40 minutes using Pyrex-filtered light. ^{1}H NMR showed the formation of **m-Me-^{i}Pr-ACB$_S$** as the only product. This product was

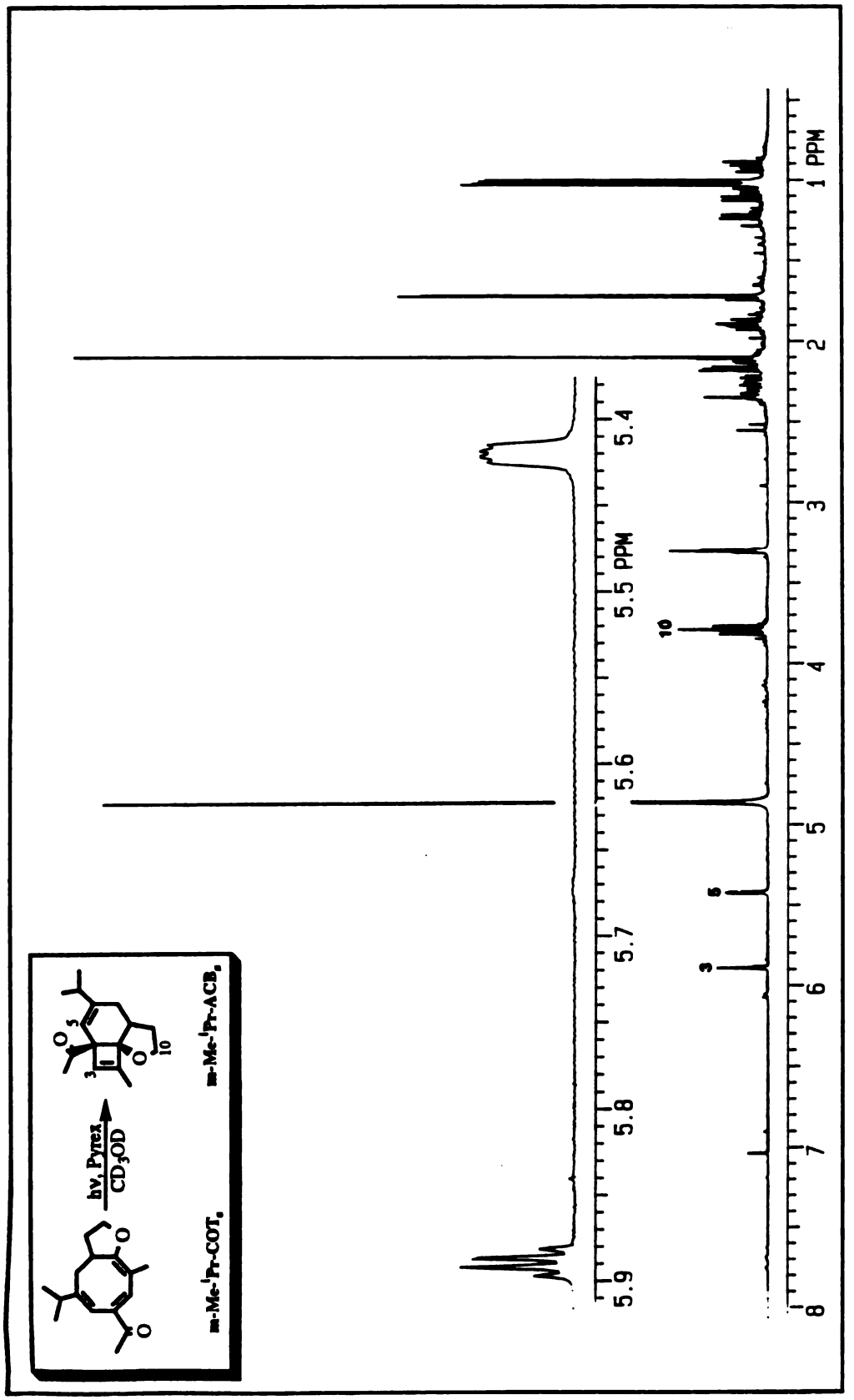
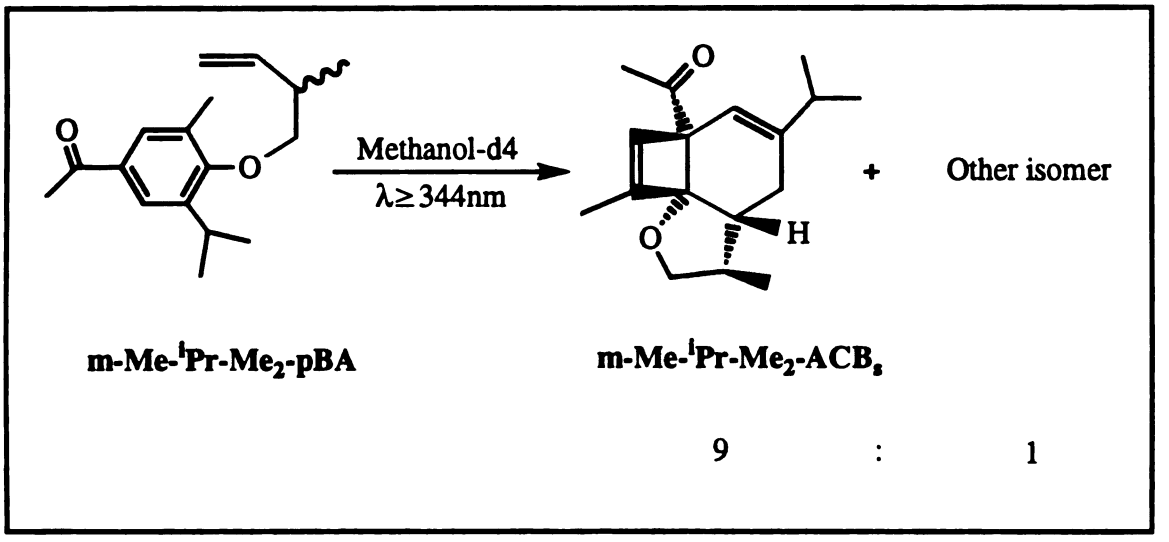


Figure 12: ^{1}H NMR spectrum of **m-Me-^{i}Pr-ACB$_4$** obtained by irradiation of **m-Me-^{i}Pr-COT$_4$** in benzene-d_6 using Pyrex-filtered light.

found to be stable to heat, as it remained unchanged when heated at 100°C for one hour or left at room temperature in the dark for four days. This result contradict a previous result which showed that another sample of **m-Me-^{i}Pr-ACB$_S$** isomerized to **m-Me-^{i}Pr-COT$_S$** when treated similarly. The only difference in the conditions under which these samples of **m-Me-^{i}Pr-ACB$_S$** was subjected was the use of different ampoule of methanol-d_4.

Photochemistry of **m-Me-^{i}Pr-Me$_2$-pBA**

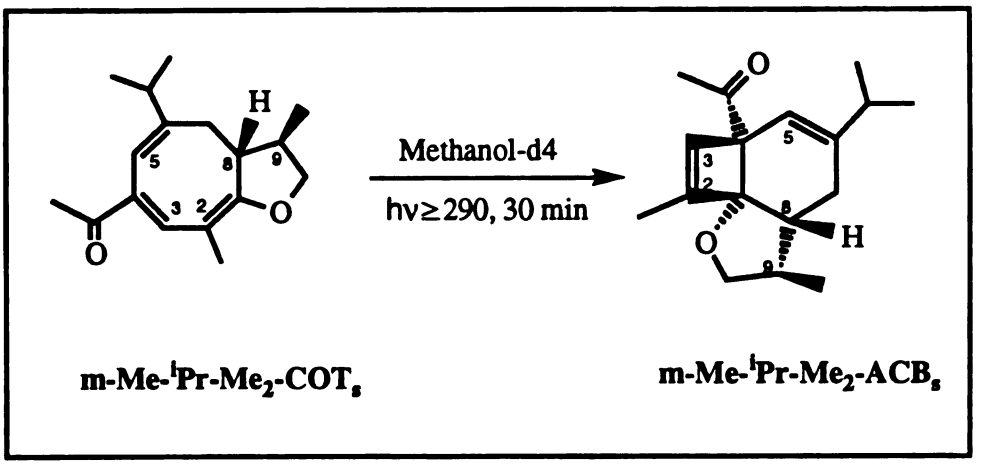


Scheme 73

In an NMR tube a solution of **m-Me-^{i}Pr-Me2-pBA** was irradiated at $\lambda \geq$ 334 nm. ^{1}H NMR showed the formation of 4-acetyl-6-isopropyl-2-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,10-diene (**m-Me-^{i}Pr-Me2-ACB$_S$**) as the major product and another unidentified product in a ratio of 9 : 1 respectively.

Large scale irradiation (0.08 gm of **m-Me-^{i}Pr-Me2-pBA** in 150 ml of dry methanol) was carried out for 2 hours using pyrex-filtered light at low temperature (ice-salt bath). After removing the solvent, ^{1}H NMR showed the formation of **m-Me-^{i}Pr-Me2-ACB$_S$**. The photoproduct was isolated as 4-acetyl-

6-isopropyl-2,9-dimethyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Me-^{i}Pr-Me2-COTs**).

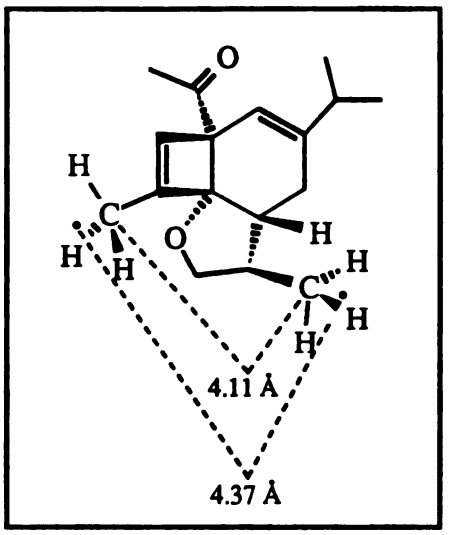


Scheme 74

In an NMR tube a solution of **m-Me-^{i}Pr-Me2-COTs** (3.1 mg in 0.75 ml methanol-d4) was purged with argon and irradiated at $\lambda \geq 290$ nm. After 30 minutes, ^{1}H NMR showed the formation of **m-Me-^{i}Pr-Me2-ACBs**

The two products were identified by ^{1}H NMR. **m-Me-^{i}Pr-Me2-ACBs** (methanol-d4) has two olefinic protons; a doublet of doublets (J = 2.8, 0.9 Hz) at 5.42 ppm (H_5) and a quartet (J = 1.54 Hz) at 5.87 ppm (H_3). From the coupling constants it was suggested that this cyclobutene is a result of the double bond addition to the benzene ring towards the isopropyl group (compared to **m-Me-^{i}Pr-ACBs**). The stereochemistry of **m-Me-^{i}Pr-Me2-ACBs** was determined using a ^{1}H NMR nOe experiment at 25°C (methanol-d_4, 500 MHz). Irradiation of the methyl group at C_9 (1.0 ppm) induced enhancement of H_8 (3.03%) and $H_{10\beta}$ (2.4%) while irradiation of C_8 (1.87 ppm) caused enhancement of the methyl group at 1.0 ppm (4.33%) and $H_{10\beta}$ (1.16%). This indicates that the methyl group at C_9 is syn to the bridgehead proton H_8. No enhancement was observed for the methyl group at C_2. This is due to the large distance between the two groups. The

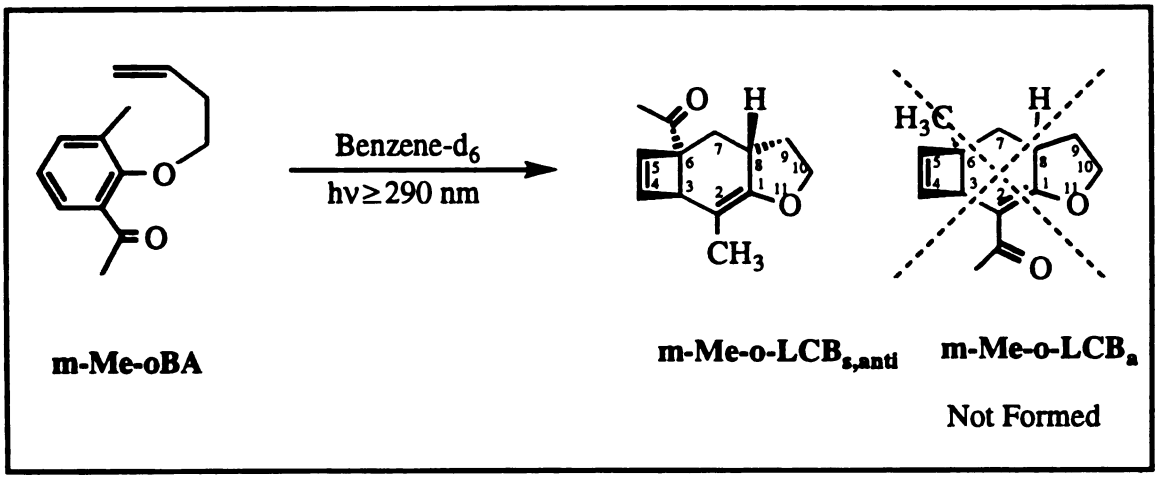
distance between the centroids of the three hydrogen atoms of the two methyl groups was calculated to be 4.37 Å (Scheme 75). The distance between any two hydrogen atoms was not considered since the rotational motion of the methyl groups will be very fast compared to the relaxation rate of the single proton and the net effect at the single proton must be averaged over this motion.[92,93]



Scheme 75

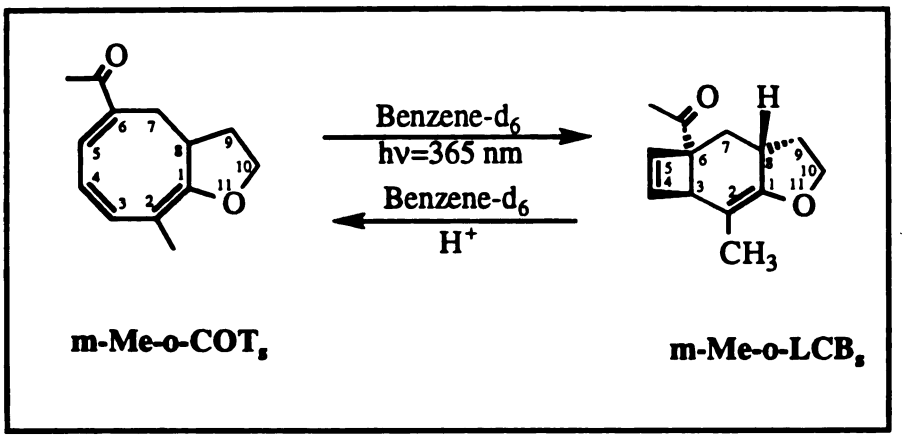
m-Me-^{i}Pr-Me2-COTs (methanol-d_4) has two olefinic protons: a broad singlet at 6.06 ppm (H_5) and a singlet at 7.05 ppm (H_3). Homonuclear decoupling NMR experiment showed that H_5 couples to $H_{7\alpha}$, $H_{7\beta}$ and the isopropyl methine. The stereochemistry of **m-Me-^{i}Pr-Me2-COTs** was determined using a ^{1}NMR nOe experiment at 25°C (methanol-d_4, 500 MHz). Irradiation of the bridgehead proton H_8 lead to the enhancement of the methyl group at C_9 (2.61%), H_3 (1.06%), H_9 (1.02%) and $H_{10\beta}$ (1.02%). Irradiation of H_9 caused the enhancement of H_8 (1.17%), $H_{10\alpha}$ (4.05%), $H_{7\alpha}$ (2.04%) and the methyl group attached to C_9 (3.02%). Irradiation of the methyl group attached to C_9 lead to the enhancement of H_8 (2.9%), $H_{10\beta}$ (1.9%), H_9 (2.7%) and $H_{7\beta}$ (1.27%). This indicates that the methyl group at C_9 is syn to the bridgehead proton, H_8.

Photochemistry of m-Me-oBA



Scheme 76

Irradiation of **m-Me-oBA** in benzene-d_6 in NMR tube through pyrex-filtered light provided 6-acetyl-2-methyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-Me-o-LCB$_{s,anti}$**) as the only product. This cyclobutene is a result of the double bond addition to the benzene ring towards the acetyl group. The other regioisomer; 2-acetyl-6-methyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-Me-o-LCB$_a$**) was not detected by ^{1}H NMR. When a catalytic amount of *p*-toluenesulfonic acid was added to a **m-Me-o-LCB$_{s,anti}$** solution in benzene-d_6, yellow color was developed immediately. ^{1}H NMR showed the formation of 6-acetyl-2-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Me-o-COT$_s$**). Again, the other regioisomer, 2-acetyl-6-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Me-o-COT$_a$**), was not detected by NMR.



Scheme 77

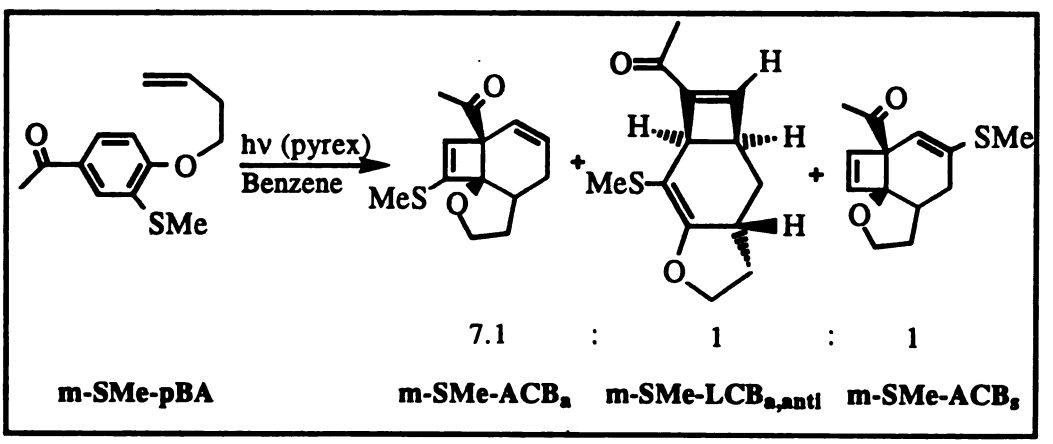
Structural differentiation between the regioisomers was based on ^{1}H NMR coupling constants and chemical shifts of selected protons. For **m-Me-o-LCB$_{s,anti}$** (benzene-d_6), there are two olefinic protons: a doublet (J = 2.88 Hz) at 5.81 ppm (H_5) and a doublet of doublets (J = 2.88, 0.89 Hz) at 5.93 ppm (H_4). The 2.88 Hz coupling constant is typical for cyclobutene vinylic protons The methyl group at C_2 of **m-Me-o-LCB$_{s,anti}$** appears as a doublet (J = 2.21 Hz) at 1.81 ppm due to the allylic character. The 2.21 Hz coupling constant is due to the homoallylic coupling with H_8. On the other hand, **m-Me-o-LCB$_a$** would have the methyl group on C_6 and it would be a singlet at about 1.0 ppm.

The stereochemistry of **m-Me-o-LCB$_{s,anti}$** was determined using a ^{1}H NMR nOe experiment at 15°C (benzene-d_6, 500 MHz). Irradiation of H_4 (H_5 was partially irradiated) led to the enhancement of H_3 (5.8%) and H_8 (1.75%). Irradiation of H_5 (H_4 was partially irradiated) induced enhancement of H_3 (2.4%), H_8 (4.1%) and the acetyl group (2.5%). Irradiation of H_3 led to the enhancement of H_4 (8.0%), CH_3 (6.5%), acetyl group (6.1%) and H_8 (1.0%). Irradiation of H_8 induced enhancement of H_4 (2.0%), H_5 (3.71%), $H_{10\beta}$ (1.94%). These results indicates that the bridgehead proton H8 is syn to the cyclobutene ring.

The other product, **m-Me-o-COT$_S$** has three olefinic protons (chloroform-*d*): a doublet of doublets (J = 12.37, 6.8 Hz) at 5.9 ppm (H_4), a doublet (J = 12.36 Hz) at 6.04 ppm (H_3) and a doublet (J = 6.80 Hz) at 7.0 ppm (H_5). H_5 has a chemical shift of 7.0 ppm as a result of being conjugated with the acetyl group. On the other hand, the other regioisomer **m-Me-o-COT$_a$** would have a methyl group on C_6, thus, H_5 would be a broad singlet (doublet of doublet of quartet with allylic coupling constants) with chemical shift about 6.0 ppm (compare to **m-Me-COT$_S$**)

Large scale irradiation of **m-Me-oBA** (0.3 gm in 150 ml dry benzene) was carried using Pyrex-filtered light. Solvent was removed and photoproduct was isolated (preparatory TLC) as **m-Me-o-COT$_S$**. Irradiation of a sample of the product in benzene-d_6 (λ = 365) led to its complete conversion to **m-Me-o-LCB$_{s,anti}$**.

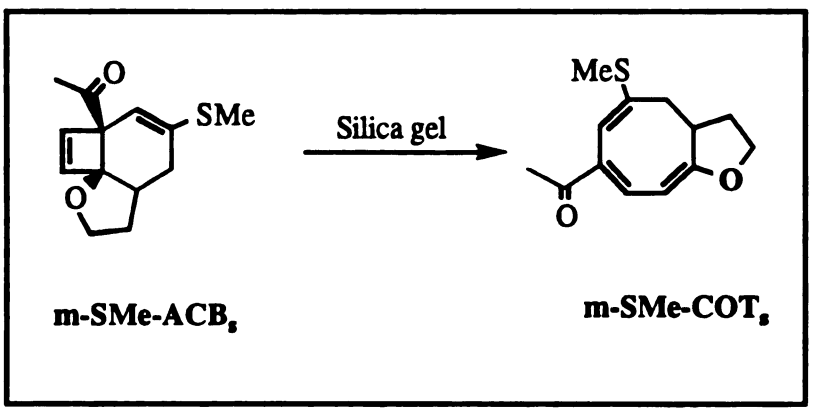
Photochemistry of m-SMe-pBA



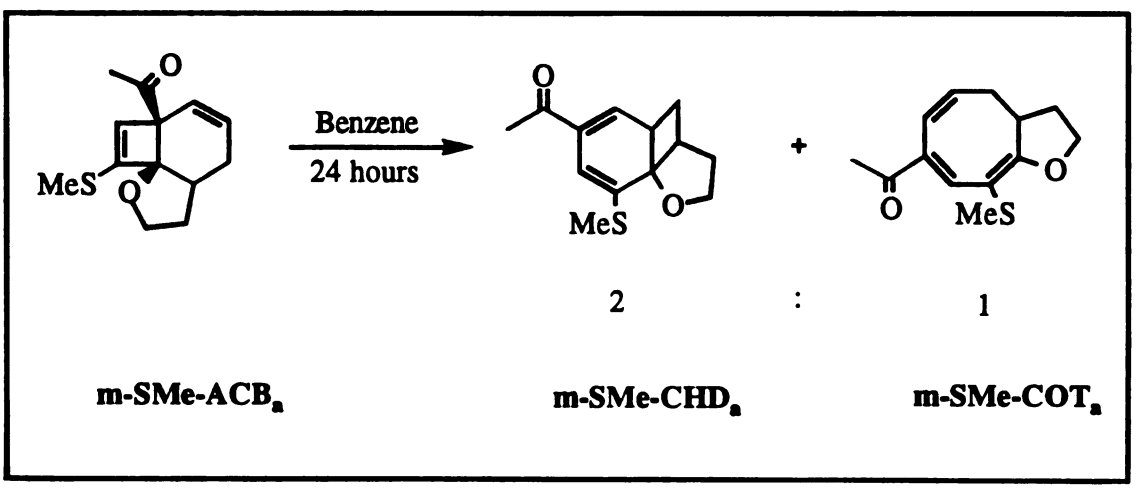
Scheme 78

A solution of **m-SMe-pBA** in benzene-d_6 was irradiated with Pyrex-filtered light. After one hour of irradiation at room temperature, ^{1}H NMR showed

the formation of three products: 4-acetyl-2-methylmercapto-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-SMe-ACB$_a$**), 4-acetyl-6-methylmercapto-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-SMe-ACB$_s$**) and 4-acetyl-2-mercaptomethyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-SMe-LCB$_a$**) in a ratio of 7.5 : 1 : 1.



Scheme 79



Scheme 80

Large scale irradiation (0.3 gm in 150 ml dry benzene) was carried out for 6 hours using Pyrex-filtered light. ^{1}H NMR showed the formation of the previous

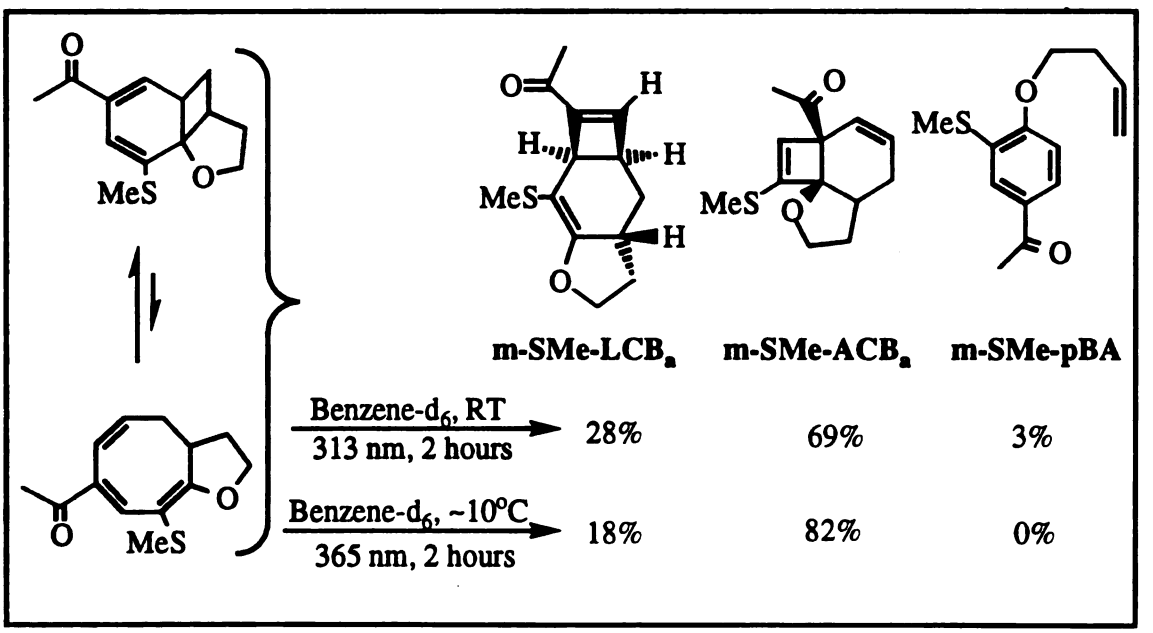
three products (note that excessive irradiation led to the disappearance of **m-SMe-ACB$_a$**). When the reaction mixture was left in the refrigerator for 24 hours, ^{1}H NMR showed the disappearance of **m-SMe-ACB$_a$** and the formation of 4-acetyl-2-mercaptomethyl-11-oxa-tricyclo[6.3.0.0^{1,6}]undeca-2,4-diene (**m-SMe-CHD$_a$**) and 4-acetyl-2-mercaptomethyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-SMe-COT$_a$**). Preparative TLC led to the isolation of **m-SMe-LCB$_a$**, a **m-SMe-CHD$_a$/m-SMe-COT$_a$** mixture, and 4-acetyl-6-mercaptomethyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-SMe-COT$_s$**).

All Photoproducts were identified by ^{1}H NMR spectroscopy. **m-SMe-ACB$_a$** has three olefinic protons: a singlet at 5.7 ppm (H_3), a ddd at 5.75 ppm (H_6) and a ddd at 5.99 ppm (H_5). H_5 and H_6 are coupled to each other with a J value of 9.28 Hz . **m-SMe-ACB$_s$** has three olefinic protons: a broad doublet (J = 2.35 Hz) at 5.36 ppm (H_5), a doublet (J = 2.8 Hz) at 5.86 ppm (H_3) and a doublet of doublet (J = 2.8, 0.55 Hz) at 6.0 ppm (H_2). The 2.8 Hz coupling constant is characteristic of cyclobutene olefinic protons.

m-SMe-LCB$_{a,anti}$ has only one olefinic proton that appears as a doublet (J = 1.35 Hz) at 6.08 ppm (benzene-d_6) and at 6.80 ppm (H_5) (chloroform-d). H_5 couples to H_6 with a J value of 1.35 Hz since the dihedral angle between the two protons is ~70^o (AM1 calculation). The stereochemistry of **m-SMe-LCB$_{a,anti}$** was determined using nOe experiment (benzene-d_6, 15^{o}C). Irradiation of the bridgehead proton H_3 (3.71 ppm, $H_{10\beta}$ was partially irradiated) induced enhancements of H_6 (6.92%) and the thiomethoxy group (2.0%). Similarly irradiation of H_6 (2.62 ppm, thiomethoxy group was partially irradiated) led to the enhancement of H_3 (8.9%), $H_{7\beta}$ (0.83%) and $H_{7\alpha}$ (2.34%). Irradiation of H_5 led to the enhancement of H_6 (2.9%), $H_{7\beta}$ (0.60%), acetyl group (2.41%) and H_8 (0.8 %). This indicates that the cyclobutene ring is syn to the bridgehead proton H_8.

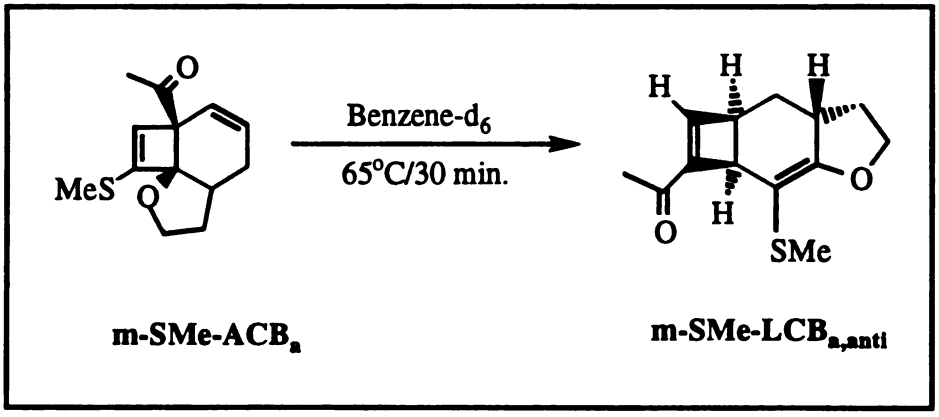
m-SMe-COT$_S$ has three olefinic protons (chloroform-*d*); a doublet of doublets at 5.50 ppm (J = 9.05, 2.43 Hz) (H_2), a broad singlet at 6.06 ppm (H_5) and a doublet of doublets at 6.96 ppm (J = 9.05, 0.88 Hz) (H_3). The 9.05 Hz coupling constant is due to the vicinal coupling between H_2 and H_3. H_3 also couples to the bridgehead proton H_8 with an allylic coupling constant of 2.43 Hz.

It should be noted that **m-SMe-CHD$_a$** and **m-SMe-COT$_a$** were isolated as a 2:1 mixture (^{1}H NMR integration). **m-SMe-COT$_a$** has three olefinic protons (benzene-d_6): a ddd at 5.5 ppm,(J = 13.25, 4.53, 4.53 Hz) (H_6), a ddd at 6.50 ppm (J = 13.25, 2.21, 2.21 Hz) (H_5) and a singlet at 7.07 ppm (H_3). The 13.25 Hz coupling constant between H_5 and H_6 is typical for cis cyclooctene protons.[90] **m-SMe-CHD$_a$** has two olefinic protons (benzene-d_6): a doublet of doublets at 5.98 ppm (J = 5.75, 0.70 Hz) (H_5) and a doublet at 6.53 ppm (J = 0.70 Hz) (H_3). The 5.75 Hz coupling constant of H_5 is due to the vicinal coupling to the bridgehead proton H_6. The 0.70 Hz coupling constant is due to W-coupling between H_3 and H_5.



Scheme 81

m-SMe-CHD$_a$/m-SMe-COT$_a$ mixture was irradiated at two different wave lengths. A solution of the mixture in benzene-d_6 was irradiated at room temperature using 313 nm light for two hours (65% conversion). ^{1}H NMR showed the formation of **m-SMe-LCB$_{a,anti}$**, **m-SMe-ACB$_a$** and **m-SMe-pBA** in a ratio of 28 : 69 : 3. When irradiation was performed using 365 nm light for 2 hours at 10°C, ^{1}H NMR showed the disappearance of starting material and the formation of **m-SMe-LCB$_{a,anti}$** and **m-SMe-ACB$_a$** in a ratio of 18 : 82



m-SMe-ACB$_a$ **m-SMe-LCB$_{a,anti}$**

Scheme 82

In order to study the thermal chemistry of **m-SMe-ACB$_a$**, a sample of the compound had to prepared by irradiating the **m-SMe-CHD$_a$/m-SMe-COT$_a$** mixture (3 mg in .75 ml benzene-d_6 in an NMR tube) using 365 nm light for 2 hours. ^{1}H NMR showed the formation of **m-SMe-ACB$_a$** and **m-SMe-LCB$_{a,anti}$** in a ratio of 4 : 1. The temperature of the NMR probe was then raised to 65°C for 30 minutes. ^{1}H NMR showed the complete transformation of **m-SMe-ACB$_a$** to **m-SMe-LCB$_{a,anti}$**.

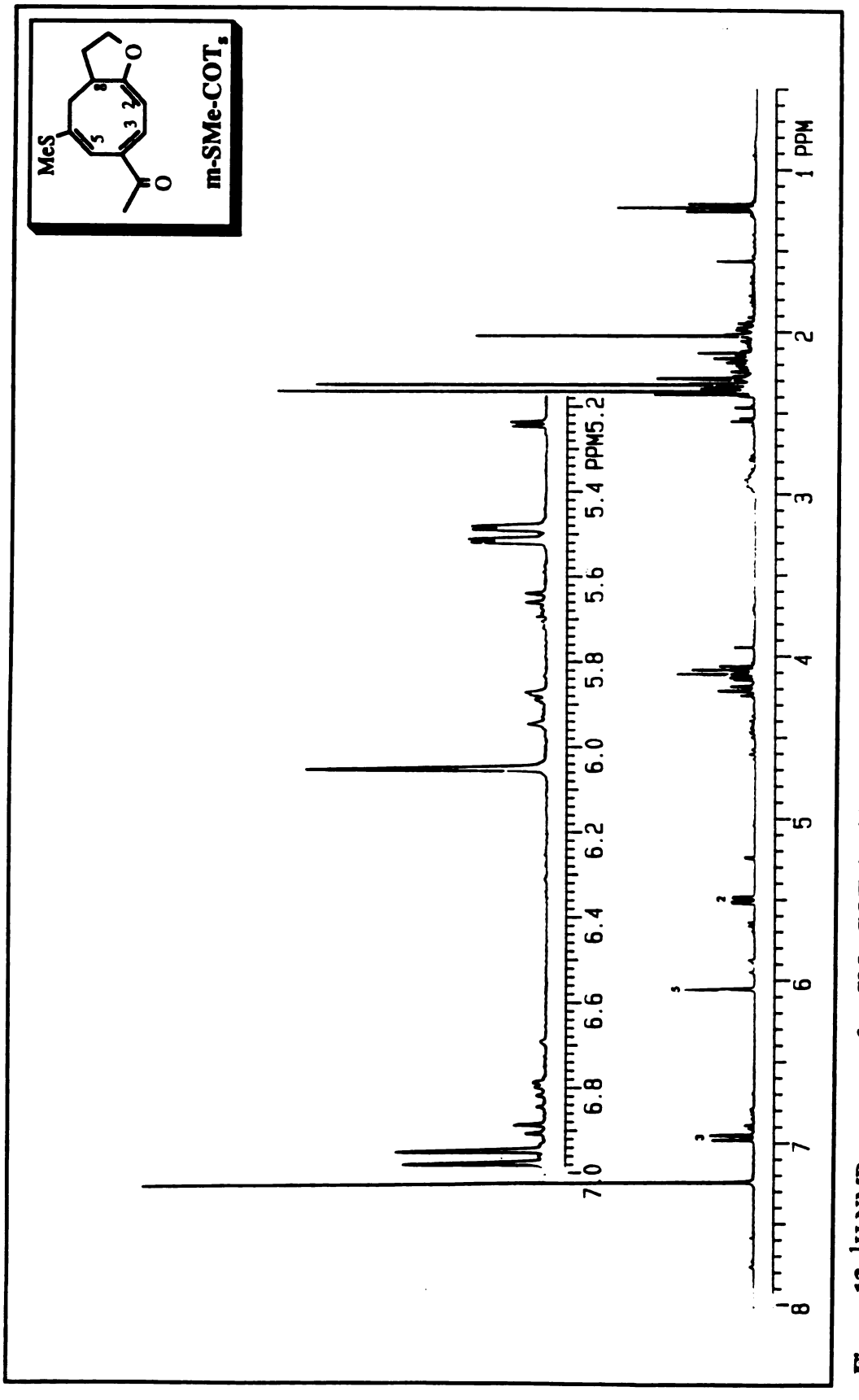


Figure 13: ^{1}H NMR spectrum of **m-SMe-COT$_s$** in chloroform-*d*.

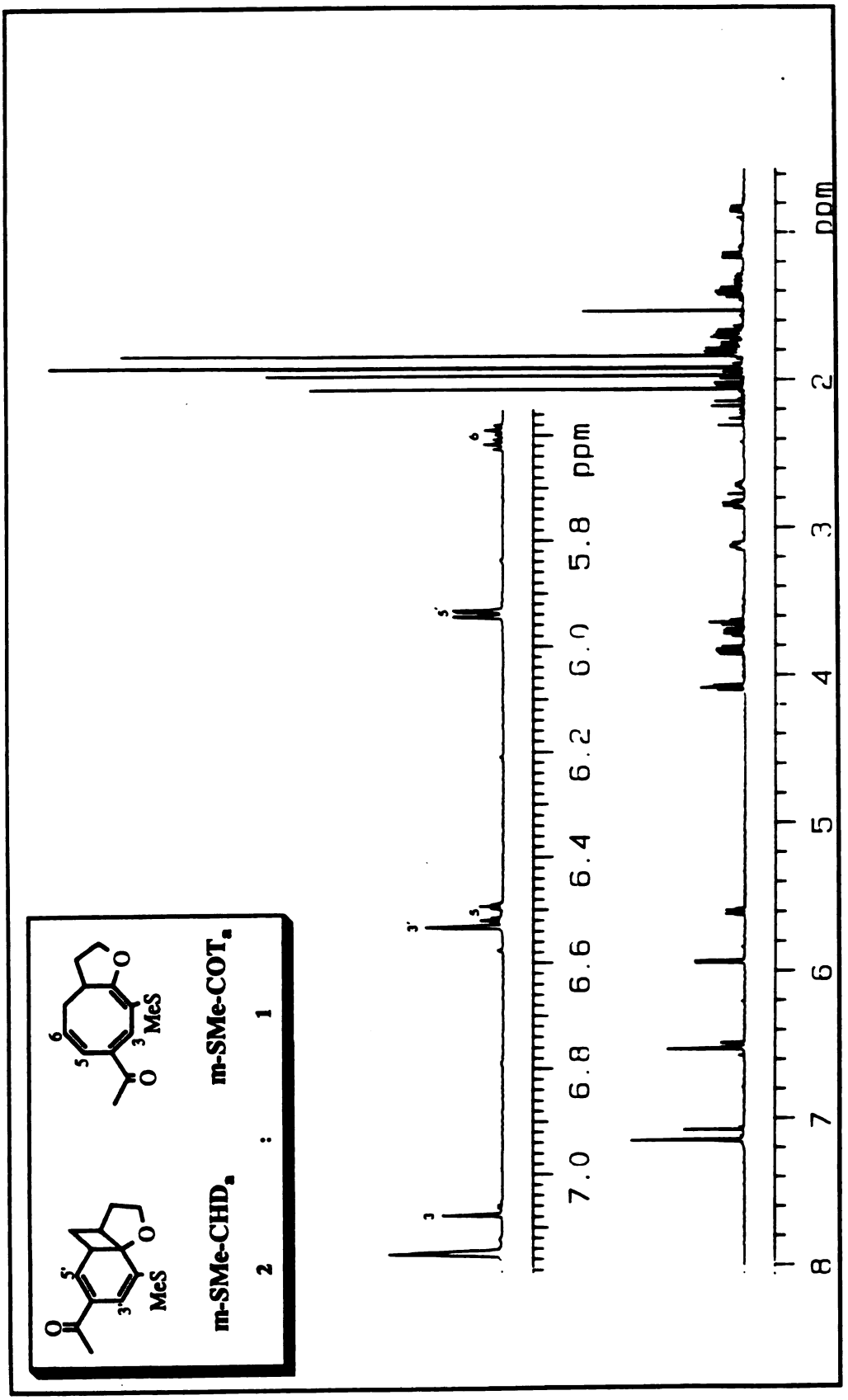


Figure 14: ^{1}H NMR spectrum of equilibrium mixture of **m-SMe-CHD$_a$** and **m-SMe-COT$_a$** in benzene-d_6.

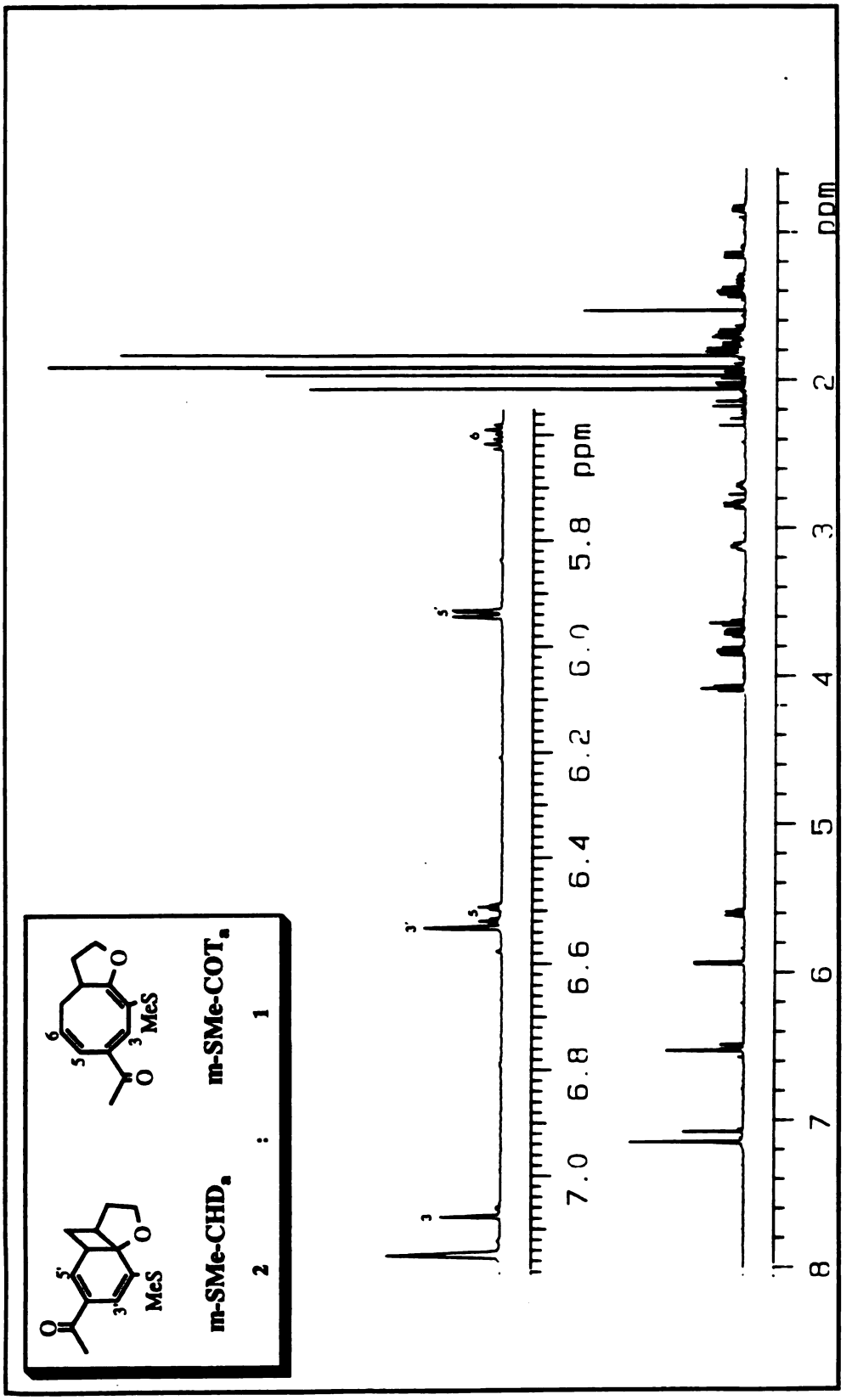


Figure 14: ^{1}H NMR spectrum of equilibrium mixture of **m-SMe-CHD$_a$** and **m-SMe-COT$_a$** in benzene-d_6.

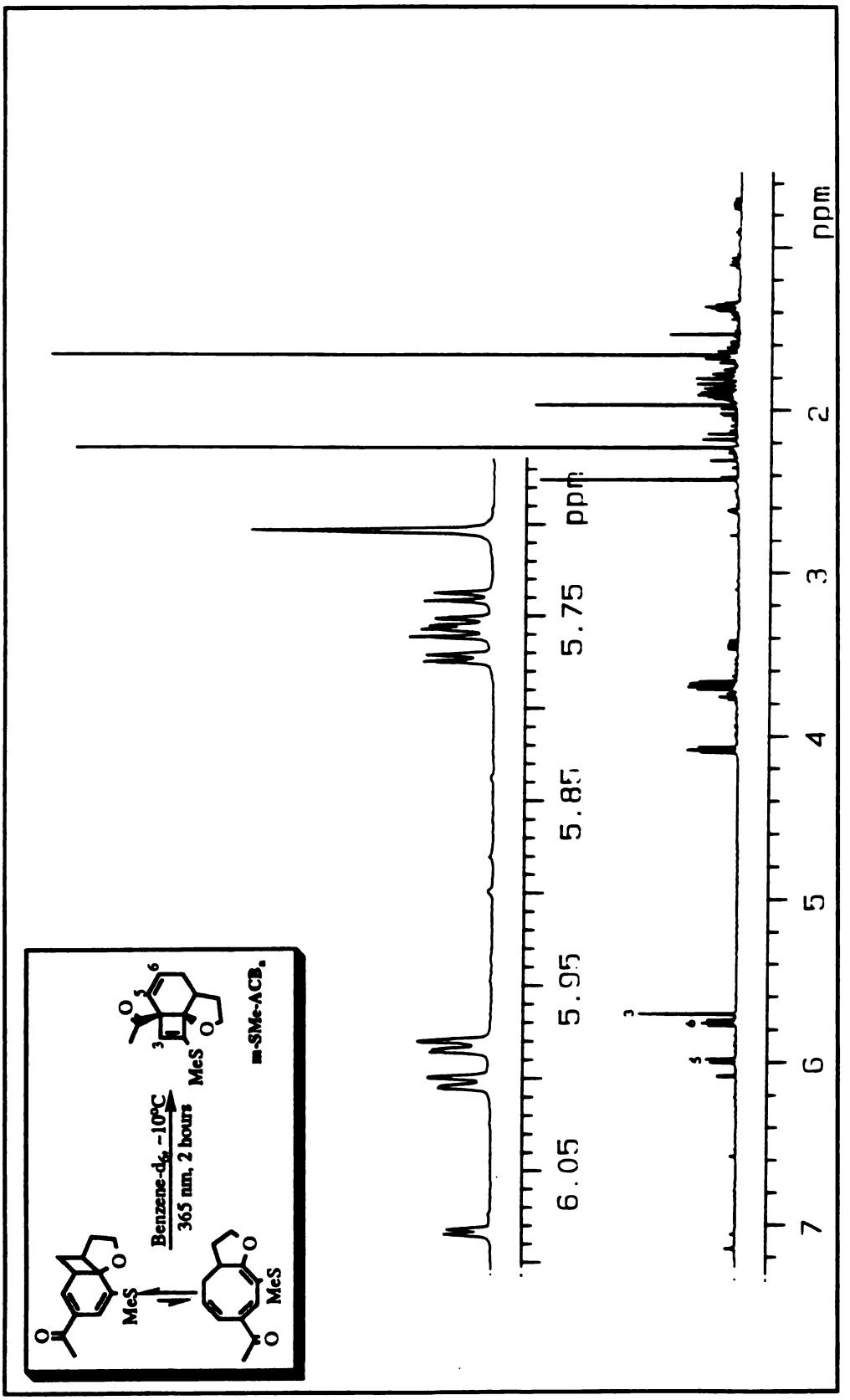
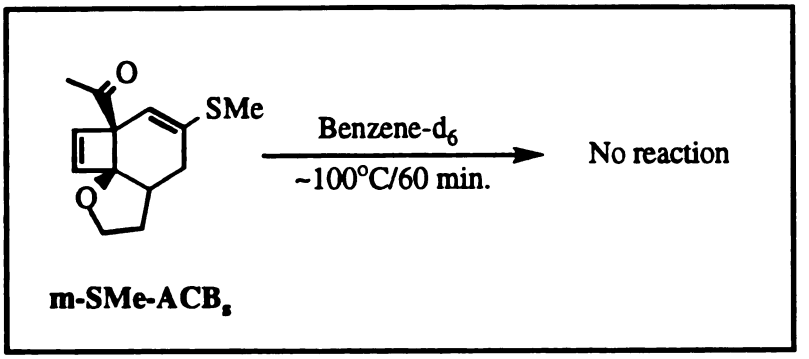


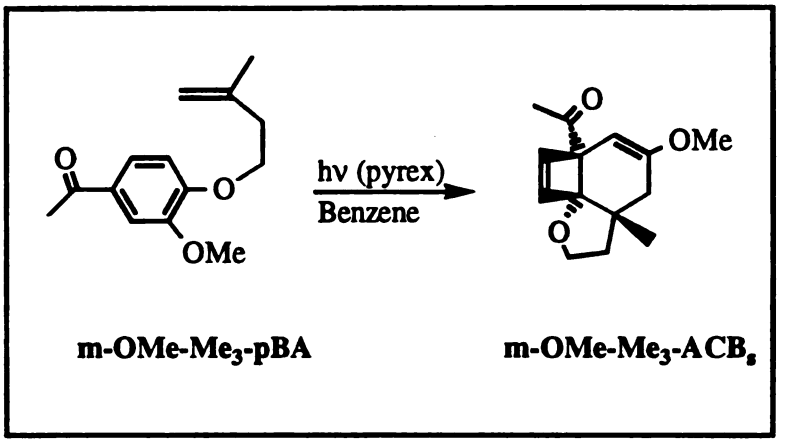
Figure 15: ^{1}H NMR spectrum of **m-SMe-ACB$_a$** obtained by irradiation of a mixture of **m-SMe-CHD$_a$** and **m-SMe-COT$_a$** in benzene-d_6 at 365 nm.



Scheme 83

On the other hand, **m-SMe-ACB$_S$** was found to be thermally more stable than its regio isomer, **m-SMe-ACB$_a$**. A solution of **m-SMe-ACB$_S$** (and other isomers) in benzene-d_6 was placed in boiling water bath for 60 minutes. ^{1}H NMR showed that **m-SMe-ACB$_S$** remained unchanged.

Photochemistry of **m-OMe-Me$_3$-pBA**

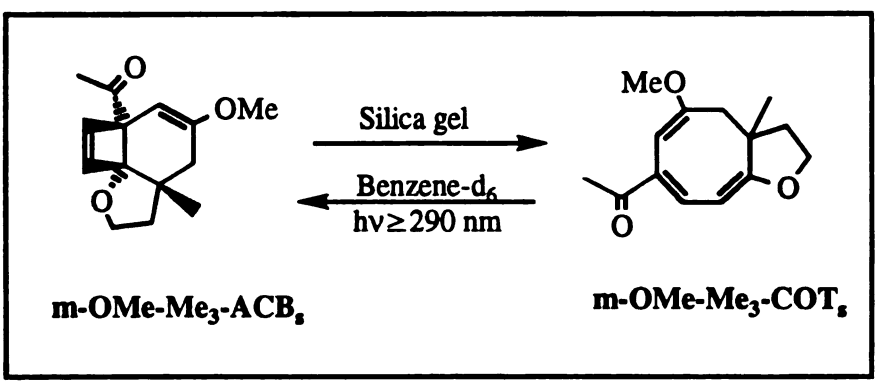


Scheme 84

Irradiation of **m-OMe-Me$_3$-pBA** (0.29 gm in 150 ml of dry benzene) was carried out using a Pyrex-filtered light ($\lambda \geq 290$ nm) under argon atmosphere. The reaction progress was monitored by ^{1}H NMR. After 15 hours irradiation, solvent

was removed under vacuum. ^{1}H NMR analysis showed the formation of 4-acetyl-6-methoxy-8-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-OMe-Me$_3$-ACB$_S$**) as the only product. Preparative TLC purification led to the isolation of the photoproduct as 4-acetyl-6-methoxy-8-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-OMe-Me$_3$-COT$_S$**)

The two products were identified by ^{1}H NMR. **m-OMe-Me$_3$-ACB$_S$** has three olefinic protons (benzene-d_6): a doublet (J = 2.0 Hz) at 4.46 ppm (H_5), a doublet (J = 2.93 Hz) at 6.0 ppm (H_2) and a doublet (J = 2.93 Hz) at 6.02 ppm (H_3). The fact that H_5 appears at 4.46 (higher field than the other protons) is due to its enol ether character. The 2.93 Hz coupling constant between H_2 and H_3 is typical for cyclobutene olefinic protons. **m-OMe-Me$_3$-COT$_S$** also has three olefinic protons ($CDCl_3$): a doublet (J = 6.2 Hz) at 5.24 ppm (H_2), a broad singlet at 5.36 ppm (H_5) and a doublet (J = 6.2 Hz) at 6.98 ppm (H_3).



Scheme 85

A solution of **m-OMe-Me$_3$-COT$_S$** in benzene-d_6 was purged with argon and irradiated with Pyrex-filtered light. After one hour of irradiation at room temperature, ^{1}H NMR showed the formation of **m-OMe-Me$_3$-ACB$_S$** at the expense of **m-OMe-Me$_3$-COT$_S$**.

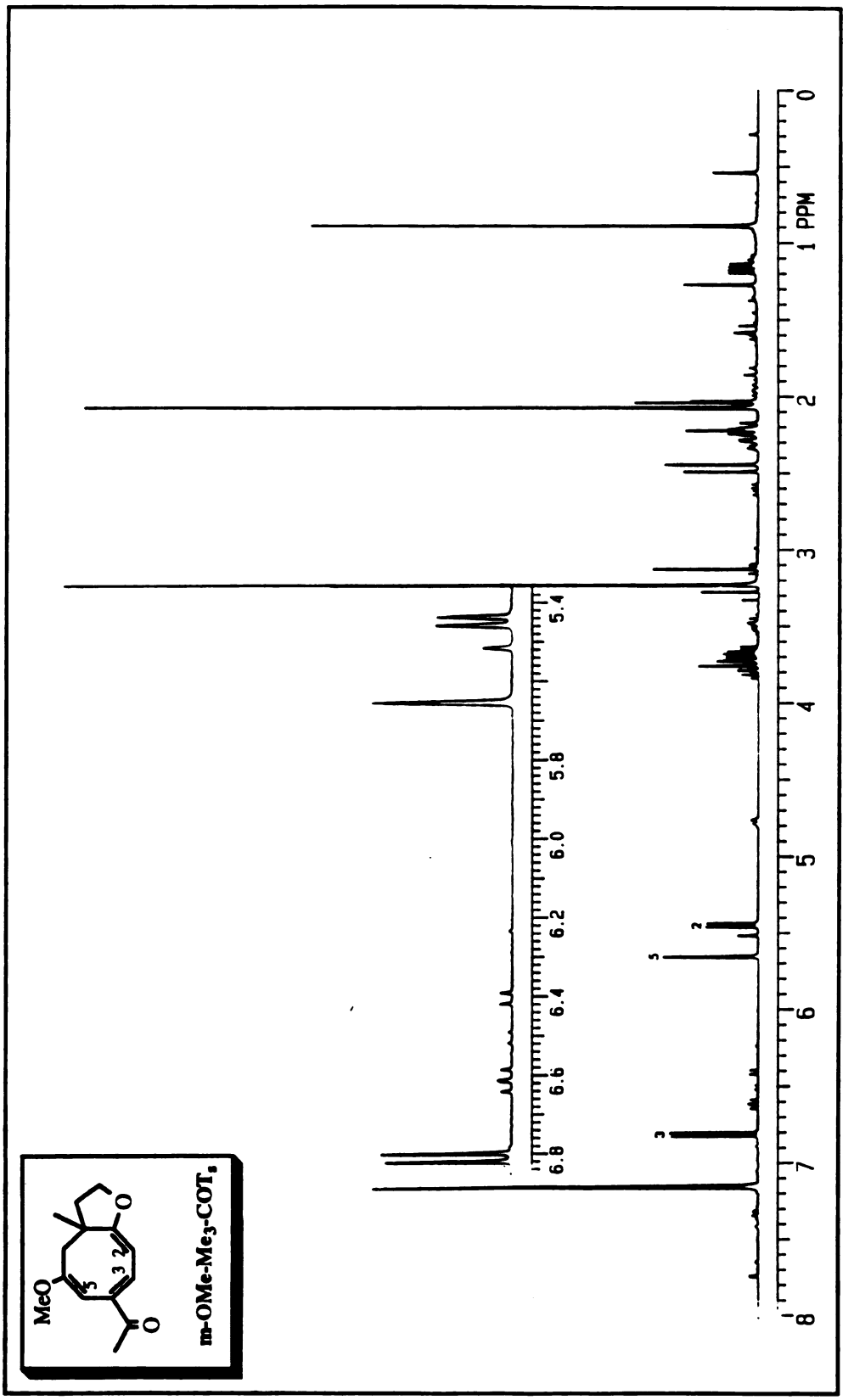


Figure 16: ^{1}H NMR spectrum of a mixture of **m-OMe-Me$_3$COT$_8$** in benzene-d_6

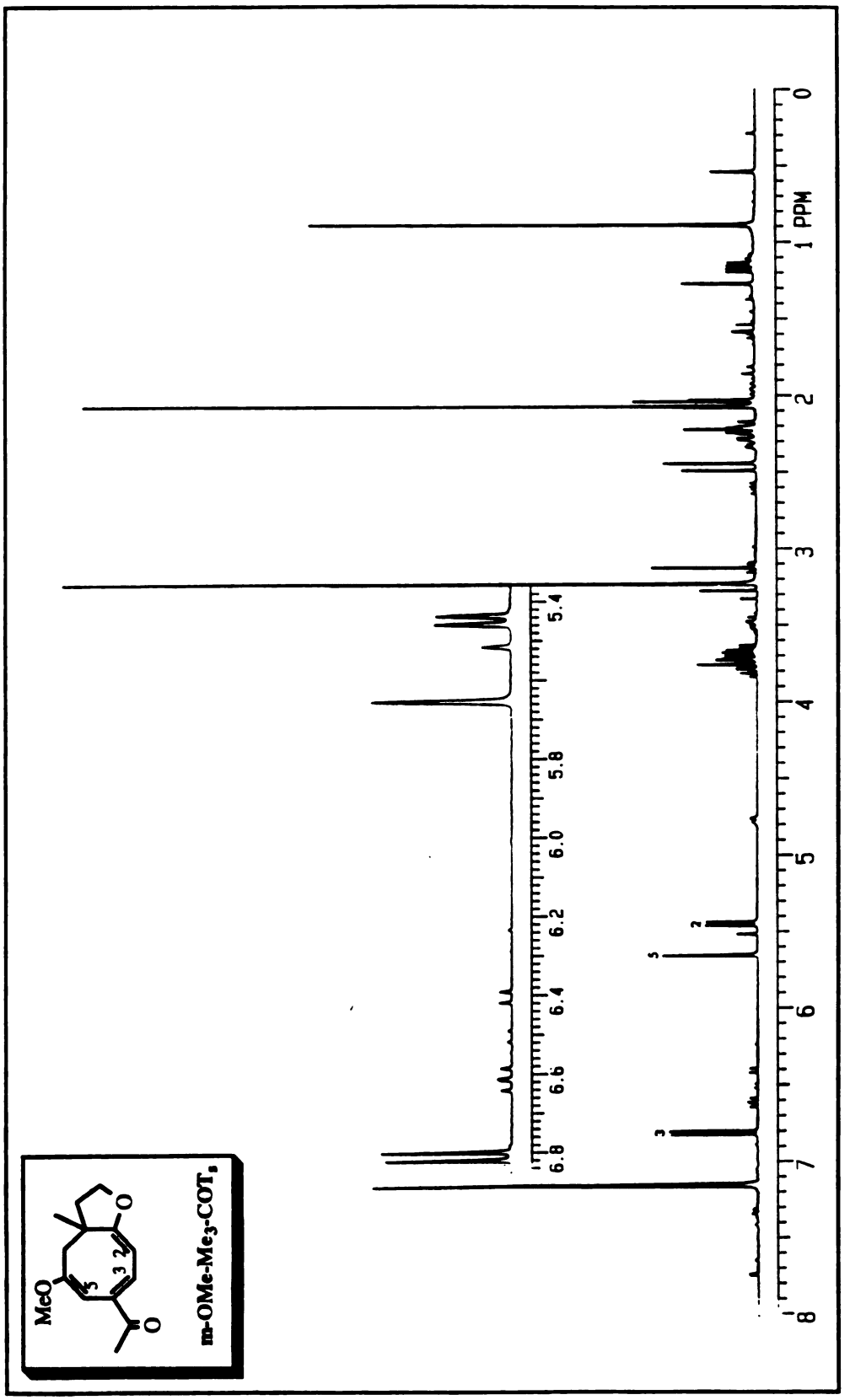
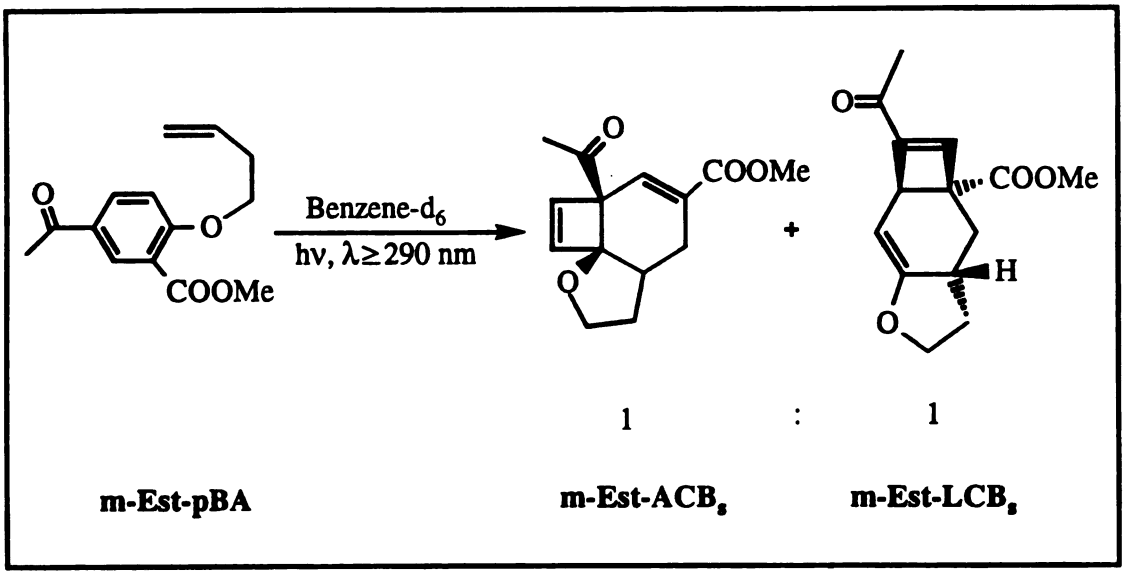


Figure 16: ^{1}H NMR spectrum of a mixture of **m-OMe-Me$_3$COT$_5$** in benzene-d_6

The stereochemistry of **m-OMe-Me$_3$-ACB$_S$** was determined using nOe experiment (benzene-d_6, 15°C). Irradiation of the methyl group at 0.70 ppm led to the enhancement of the doublet at 6.0 ppm (3.82%) and the doublet at 6.02 ppm (0.90%). This indicates that the cyclobutene ring is syn to the methyl group at the bridgehead carbon (C_8).

Photochemistry of m-Est-pBA

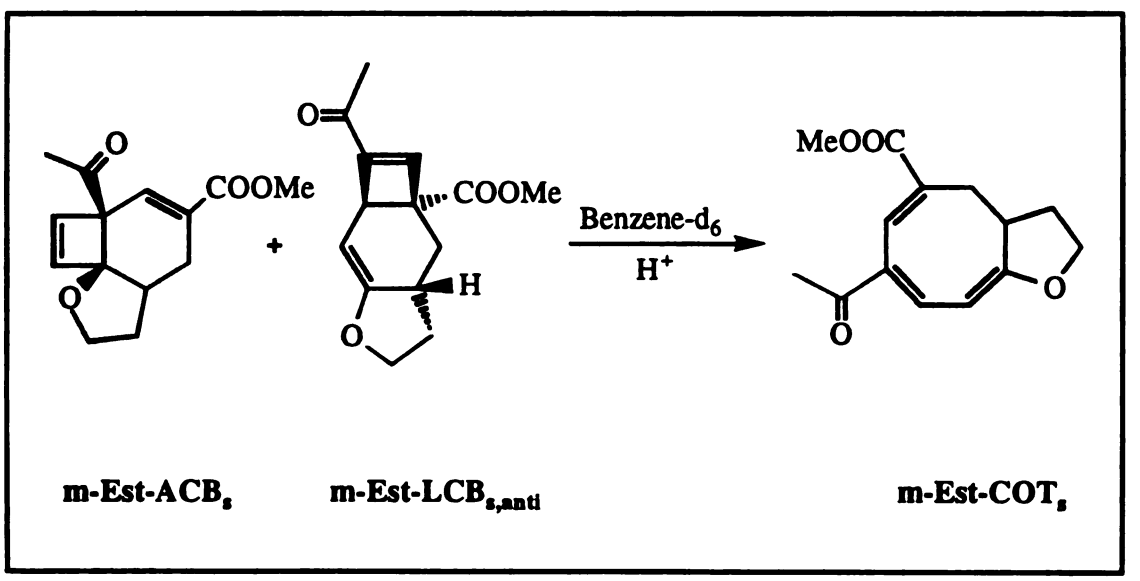


Scheme 86

Irradiation of **m-Est-pBA** in benzene-d_6 was performed using Pyrex filtered light. ^{1}H NMR spectroscopy showed the formation of 4-acetyl-6-methoxycarbonyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-Est-LCB$_{s,anti}$**) and 4-acetyl-6-methoxycarbonyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-Est-ACB$_S$**) in a ratio of 1 : 1. These products were identified from their partial ^{1}H NMR spectra. **m-Est-ACB$_S$** has three vinylic protons (benzene-d_6): a doublet of doublets (J = 2.65, 0.60 Hz) at 7.24 ppm (H_5), a doublet of doublets (J = 2.8, 0.54 Hz) at 5.98 ppm (H_2) and a doublet (J = 2.8 Hz) at 5.59 ppm (H_3). H_2 and H_3

couple to each other with a J value of 2.8 Hz. H_5 couples allylically to $H_{7\alpha}$ and $H_{7\beta}$ with a J value of 0.62 and 2.65 Hz. The 7.24 ppm chemical shift is due to conjugation with the ester group. (compared to **m-Amide-ACB$_S$**)

The other photoproduct, **m-Est-LCB$_{S,anti}$**, has two vinylic protons (benzene-d_6): a singlet at 6.22 ppm (H_5) and a doublet of doublets (J = 6.7, 2.4 Hz) at 5.38 ppm (H_2). The 6.7 Hz coupling constant between H_2 and H_3 suggests that H_8 is anti to H_3. AM1 calculation showed that the dihedral angle H_3-C_3-C_2-H_2 is 67.72° for the syn isomer and 33.34° for the anti isomer. Coupling constants were calculated, using the Karplus equation, as 5.63 Hz for the anti and 0.92 Hz for the syn isomer. The stereochemistry was also confirmed by comparing H_2-H_3 coupling constant with those of several syn and anti isomers (cf. table 8).

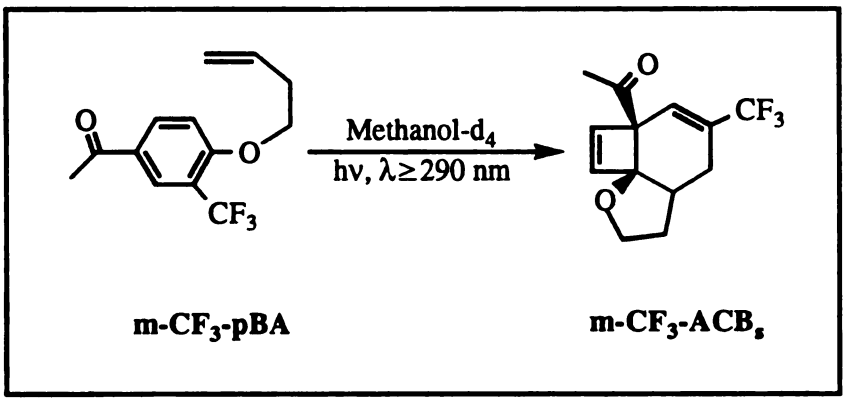


Scheme 87

Treatment of **m-Est-LCB$_{S,anti}$/m-Est-ACB$_S$** mixture with catalytic amount of *p*-toluenesulfonic acid led to the formation of 4-acetyl-6-methoxycarbonyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Est-COT$_S$**). Product was identified by its partial ^{1}H NMR spectrum (which was found to be similar to that of **m-CN-COT$_S$**).

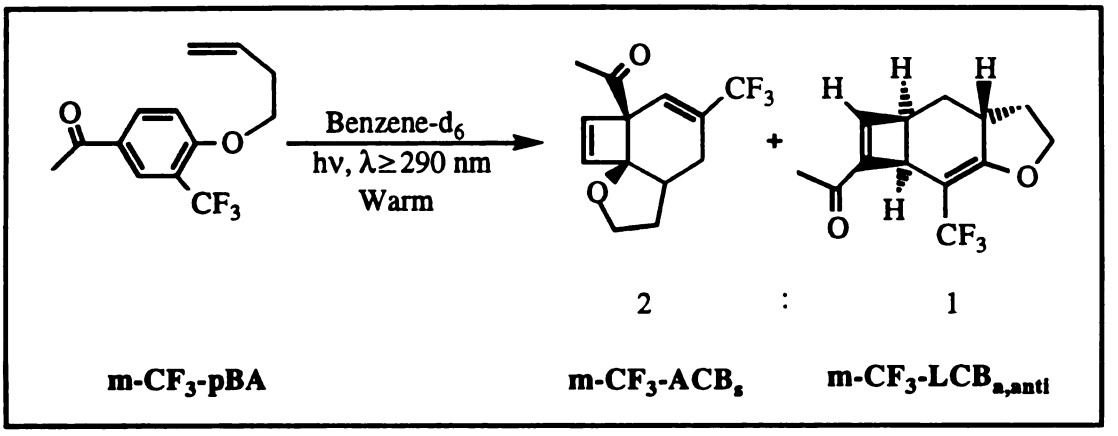
It has three vinylic protons (benzene-d_6): a singlet at 8.1 ppm (H_5), a doublet (J = 8.8 Hz) at 6.87 ppm (H_3), and a doublet of doublets (J = 8.8, 2.0 Hz) at 5.46 ppm (H_2).

Photochemistry of **m-CF_3-pBA**



Scheme 88

A methanol-d_6 solution of **m-CF_3-pBA** in an NMR tube was irradiated using Pyrex-filtered light ($\lambda \geq 290$ n.m.). After 80 minutes of irradiation, ^{1}H NMR showed the formation of 4-acetyl-6-trifluromethyl-11-oxatricyclo[6.3.0.0^{1,4}]-undeca-2,5-diene (**m-CF_3-ACB_S**). This product was identified from its partial ^{1}H NMR spectrum. It has three olefinic protons: a doublet (J = 2.96 Hz) at 6.49 ppm (H_2), a multiplet at 6.46 ppm (H_5) and a doublet (J = 2.96 Hz) at 6.33 ppm (H_3). The 2.96 Hz coupling constant is due to coupling between H_2 and H_3.

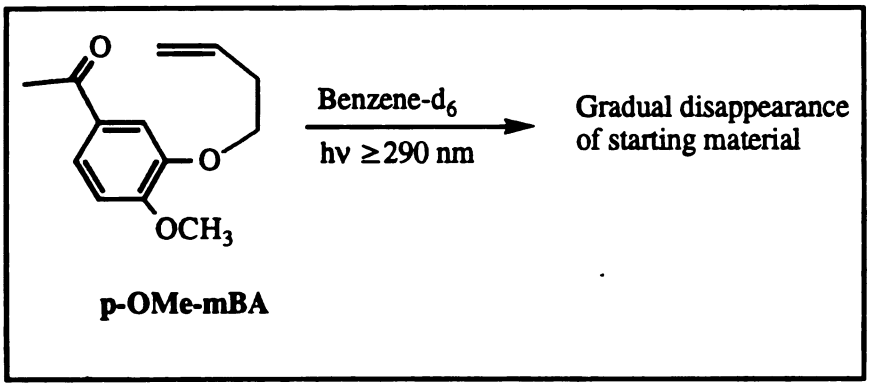


Scheme 89

Irradiation of **m-CF_3-pBA** was also done in benzene-d_6 using Pyrex-filtered light ($\lambda \geq 290$ nm). After 145 minutes, ^{1}H NMR showed the formation of **m-CF_3-ACB_S** and 4-acetyl-2-trifluoromethyl-11-oxatricyclo[6.3.0.$0^{3,6}$]undeca-1,4-diene (**m-CF_3-$LCB_{a,anti}$**) in a ratio of 2 : 1. It was identified by comparing its ^{1}H NMR spectrum with those of **m-SMe-$LCB_{a,anti}$** and **m-^{t}Bu-$LCB_{a,anti}$** (cf. table 7). The high similarity between their coupling constants suggested that they have the same stereochemistry (H_8 is anti to H_3).

The previous experiment was repeated at low temperature. The NMR tube was placed in ice-water bath during irradiation. ^{1}H NMR showed the formation of **m-CF_3-ACB_S** with only traces amount of **m-CF_3-$LCB_{a,anti}$**.

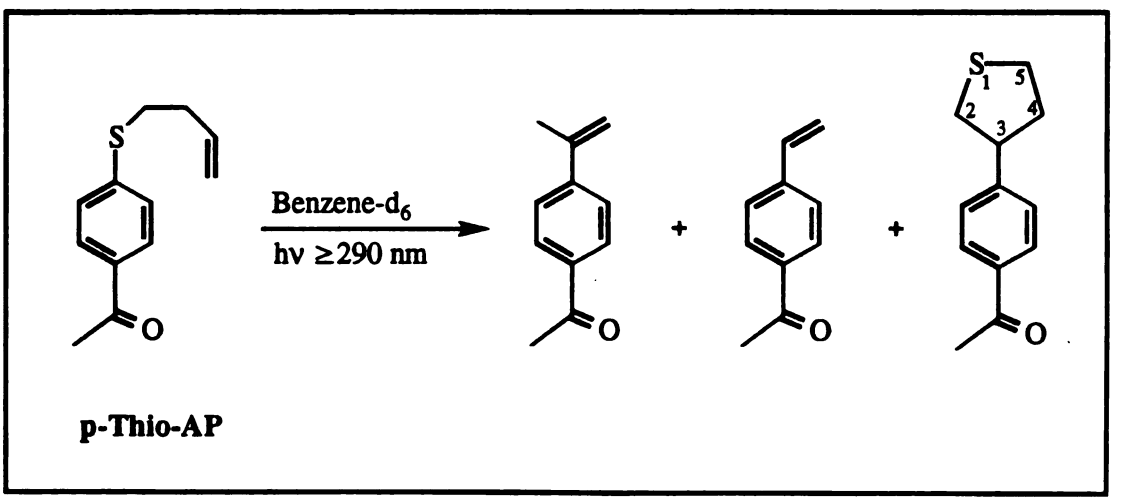
Photochemistry of p-OMe-mBA



Scheme 90

Irradiation of **OMe-m-AP** (1.2 mg in 0.75 ml benzene-d6 in an NMR tube) was performed using Pyrex filtered light ($\lambda \geq 290$ nm). ^{1}H NMR analysis showed the gradual disappearance of the starting material with the appearance of very broad signals between 0.3 and 3.5 ppm. Starting material was consumed in about 4 hours.

Photochemistry of p-Thio-AP



Scheme 91

p-Thio-AP was irradiated in benzene-d_6 in an NMR tube for 30 minutes using Pyrex-filtered light ($\lambda \geq 290$ nm). ^{1}H NMR showed the formation of three products: 3-(4-acetylphenyl)- tetrahydrothiophene, 4-acetylstyrene and 4-acetyl-α-methylstyrene.

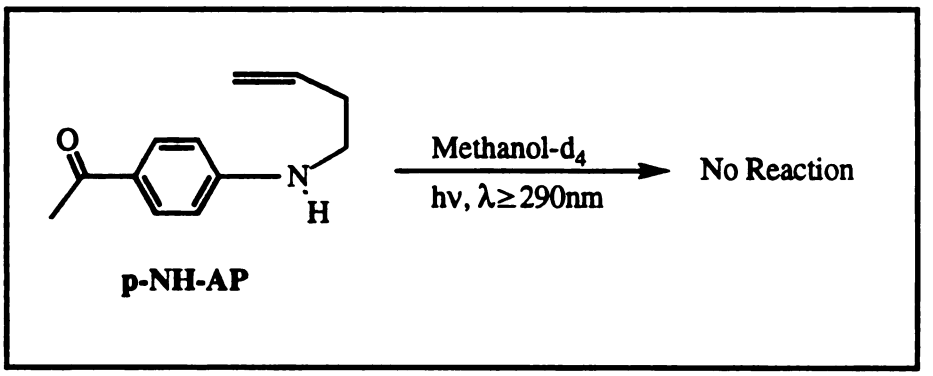
Irradiation of **p-Thio-AP** (0.62 gm in 200 ml of dry benzene, $\lambda \geq 290$ nm) was carried for three hours under argon atmosphere. After preparative TLC separation, ^{1}H NMR analysis showed the isolated products to be 4-acetylstyrene; 4-acetyl-α-methylstyrene and 3-(4-acetylphenyl)tetrahydrothiophene. 4-Acetylstyrene and 4-acetyl-α-methylstyrene were not separated from each other. ^{1}H NMR was taken for the mixture while mass spectra and hi-resolution mass spectra were aided by GC. isolation.

Mass spectrum showed that 4-acetylstyrene has molecular ion peak of 146. High resolution mass spectra suggested the molecular formula is $C_{10}H_{10}O$. ^{1}H NMR spectra ($CDCl_3$) showed the presence of three olefinic protons: a doublet of doublets (J = 10.82, 0.66 Hz) at 5.38 ppm, a doublet of doublets (J = 17.45, 0.66 Hz) at 5.88 ppm and a doublet of doublets (J = 17.45,10.82 Hz) at 6.74 ppm. This part of the spectrum suggested the presence of a monosubstituted ethylene part in the molecule. Also, a doublet (J = 8.17 Hz, 2H) at 7.47 ppm and a doublet (J = 8.17 Hz, 2H) at 7.91 ppm suggested that the molecule has *para*-disubstituted benzene unit. A singlet (3H) at 2.58 ppm along with the 7.91 ppm chemical shift of two of the aromatic protons suggested that the acetyl group is still intact.

4-Acetyl-α-methylstyrene was found to have molecular a formula of $C_{11}H_{12}O$ (High resolution Mass Spectrum). ^{1}H NMR spectrum showed the presence of two olefinic protons: a sixtet (J = 1.33 Hz) at 5.19 ppm and a doublet of quartets (J = 1.33, 0.66 Hz) at 5.46 ppm. These two protons couple to the α-methyl group at 2.16 ppm (dd, J = 1.33, 0.66 Hz).

Mass spectroscopy showed that 3-(4-acetylphenyl)-tetrahydro thiophene has the same molecular ion peak as the starting ketone, **p-Thio-AP**. ^1H NMR spectroscopy showed signals corresponding to *para*-disubstituted benzene with the acetyl group as the substituent. The rest of the spectrum shows the presence of seven aliphatic protons. Homonuclear decoupling experiment showed that H_3 couples to $H_{2\alpha}$, $H_{2\beta}$, $H_{4\alpha}$ and $H_{4\beta}$. The experiment also showed that $H_{5\alpha}$ and $H_{5\beta}$ couple only to $H_{4\alpha}$ and $H_{4\beta}$. All coupling constant were found to agree with the proposed structure.

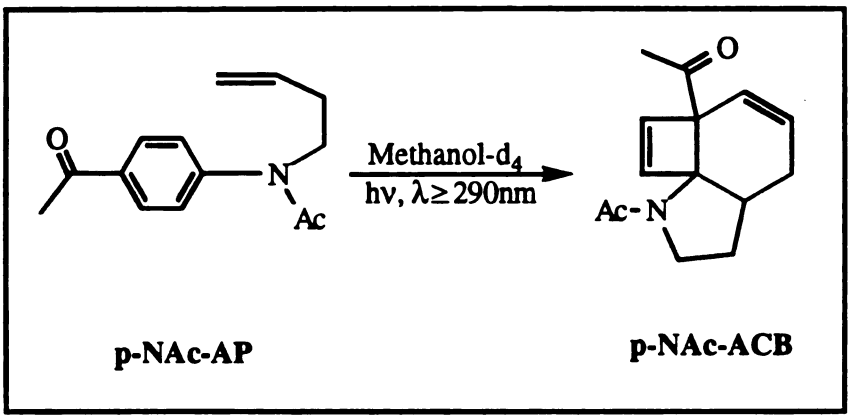
Photochemistry of **p-NH-AP**:



Scheme 92

Irradiation of **p-NH-AP** (1.2 mg in 0.75 ml methanol-d4 in an NMR tube) was performed using Pyrex filtered light. ^1H NMR Showed no reaction even after 50 hours of irradiation.

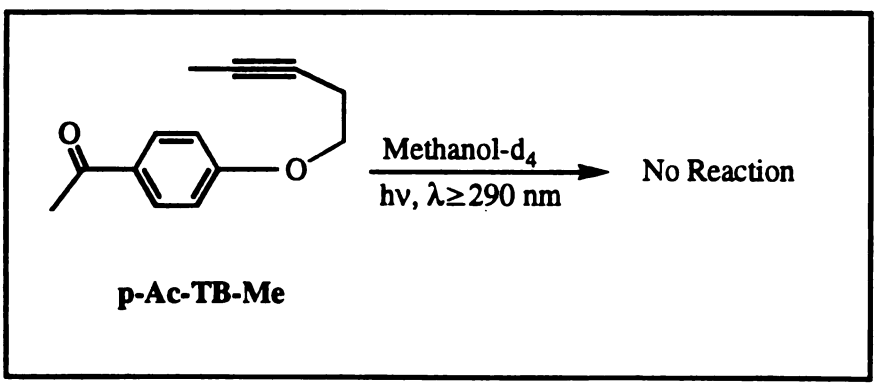
Photochemistry of **p-NAc-AP:**



Scheme 93

p-NAc-AP (1.3 mg in 0.75 ml of methanol-d4) was irradiated using Pyrex filtered light. ^{1}H NMR Showed the formation of *N*-acetyl-4-acetyl-11-azatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**p-NAc-ACB**) in low chemical yield. It was identified from its partial ^{1}H NMR spectrum. It has four olefinic protons: a multiplet at 5.52 ppm, a multiplet at 5.86 ppm, a doublet (J = 2.84 Hz) at 6.1 ppm (H_3) and a doublet (J = 2.84 Hz) at 6.37 ppm (H_2).

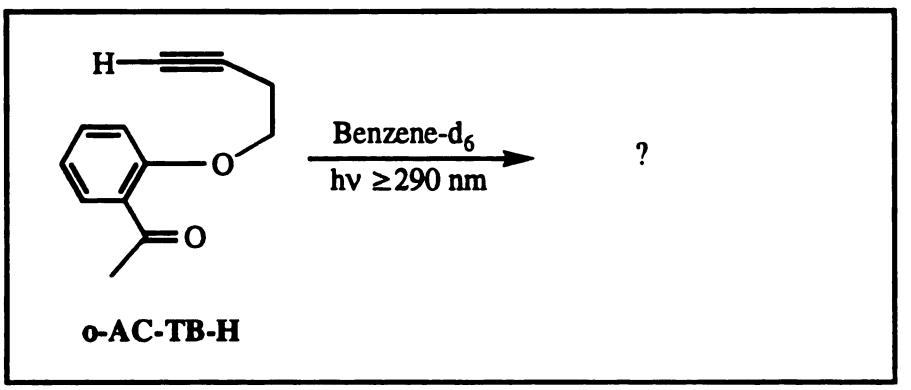
Photochemistry of **p-Ac-TB-Me**



Scheme 94

p-Ac-TB-Me Was irradiated (1.1 mg in 0.75 ml methanol-d_4 in NMR tube) using Pyrex filtered light. ^{1}H NMR showed no reaction even after 20 hours irradiation.

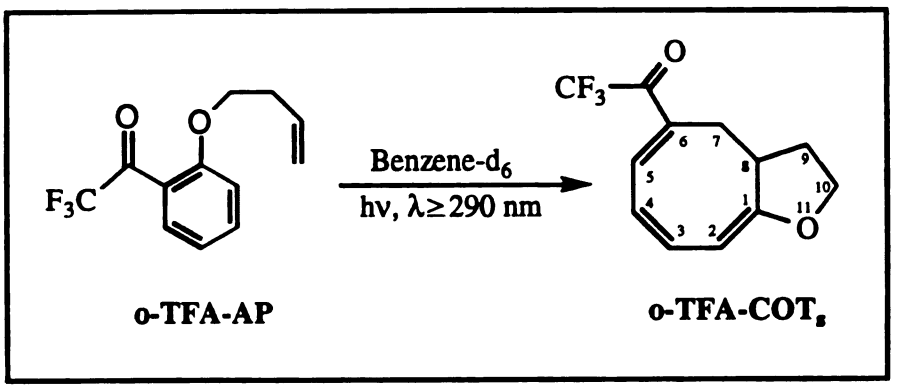
Photochemistry of o-Ac-TB-H



Scheme 95

o-Ac-TB-H was irradiated (1.1 mg in 0.75 ml benzene-d_6 in NMR tube) using Pyrex-filtered light. ^{1}H NMR showed the disappearance of peaks corresponding to starting material with the appearance of new peaks in both the aliphatic and aromatic regions. Products formed may be a result of ε hydrogen abstraction.

Photochemistry of o-BTFAc

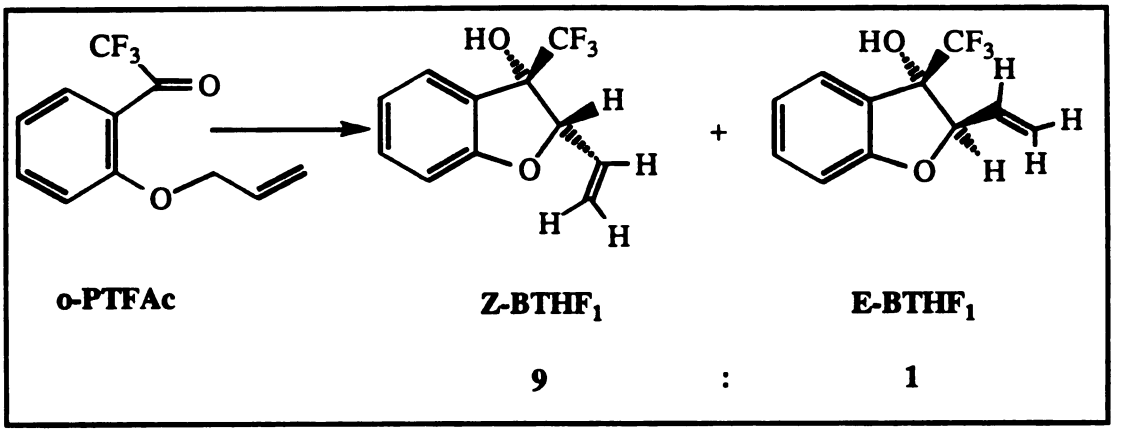


Scheme 96

A solution of **o-TFA-AP** (1.5 mg in 0.75 ml of benzene-d_6 in an NMR tube) was irradiated using pyrex-filtered light ($\lambda \geq 290$ nm). After 15 minutes of irradiation (~70% conversion), ^{1}H NMR showed the formation of 6-α,α,α-trifluoroacetyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**o-TFA-COT$_S$**). Large scale irradiation (1.0 gm in 500 ml dry benzene) also gave **o-TFA-COT$_S$** after preparatory TLC purification.

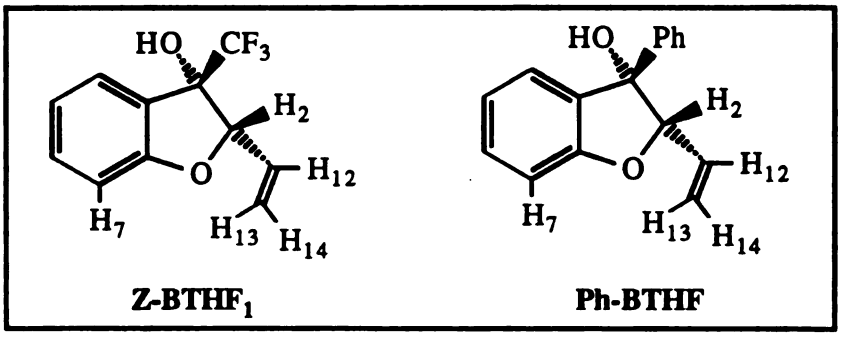
^{1}H NMR spectroscopy (chloroform-*d*) showed that **o-TFA-COT$_S$** has four olefinic protons: a doublet of doublets (J = 9.5, 1.95 Hz) at 5.46 ppm (H_2), a doublet of doublets (J = 13.25, 6.8 Hz) at 5.83 ppm (H_4), a doublet of doublets (J = 13.25, 9.50 Hz) at 6.64 ppm (H_3) and a doublet (J = 6.8 Hz) at 7.29 ppm (H_5). This spectrum is very similar to that of the acetyl analog, 6-acetyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene in chloroform-*d*.[86] ^{1}H NMR showed the presence of four olefinic protons: a doublet of doublets (J = 8.8, 1.9 Hz) at 5.34 ppm (H_2), a doublet of doublets (J = 13.0, 6.2 Hz) at 5.75 ppm (H_4), a doublet of doublets (J = 13.0, 8.80 Hz) at 6.06 ppm (H_3) and a doublet (J = 6.2 Hz) at 7.13 ppm (H_5).

Photochemistry of o-PTFAc



Scheme 97

In an NMR tube, a solution of **o-PTFAc** in benzene-d_6 was irradiated using Pyrex filtered light ($\lambda \geq 290$ nm). After 35 minutes, ^{1}H NMR showed the complete disappearance of starting material with the formation of two new compounds: *Z*- and *E*-3-hydroxy-3-trifluoromethyl-2-vinyl-2,3-dihydro-benzofuran (**Z-BTHF1** and **E-BTHF1**) in a ratio of 9 : 1 (by NMR integration of the two doublets of triplets at 5.23 and 5.28 ppm and by GC analysis). Preparatory scale irradiation led to the isolation of **Z-BTHF1** in pure form.



Scheme 98

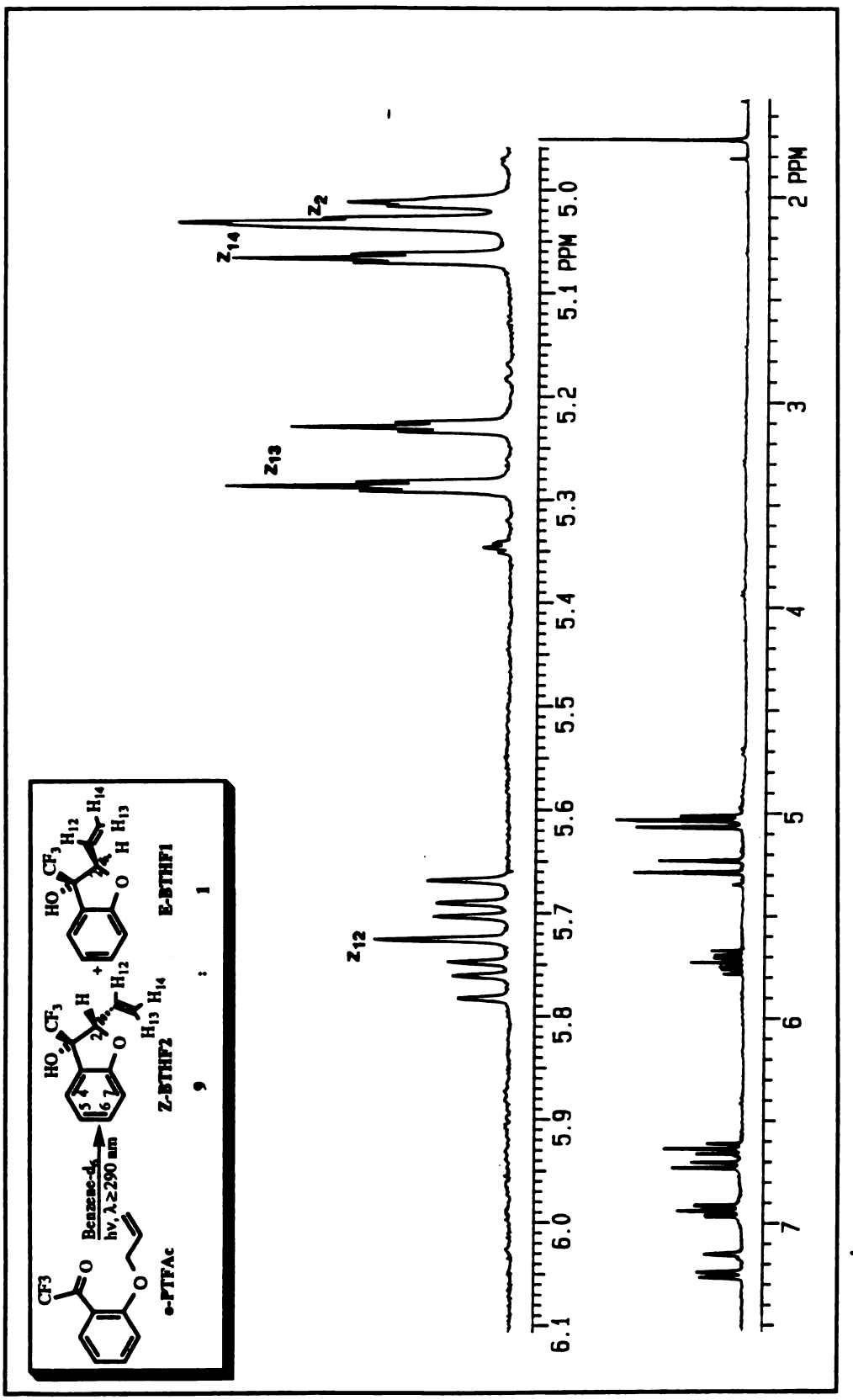


Figure 17: ^{1}H NMR spectrum of a mixture of **Z-BTHF$_1$** and **E-BTHF$_1$** obtained by irradiation of **o-PTFAc** in benzene-d_6.

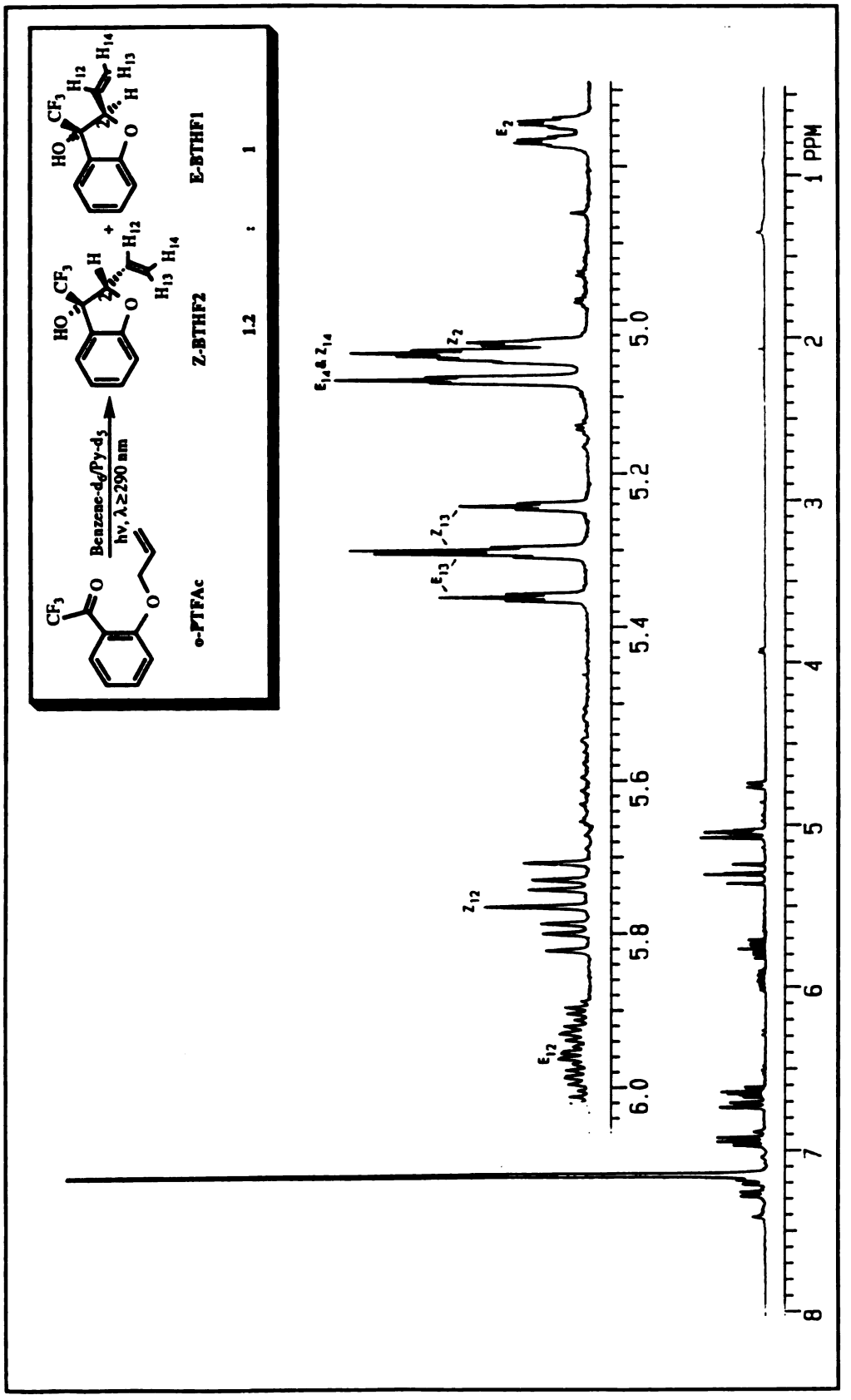
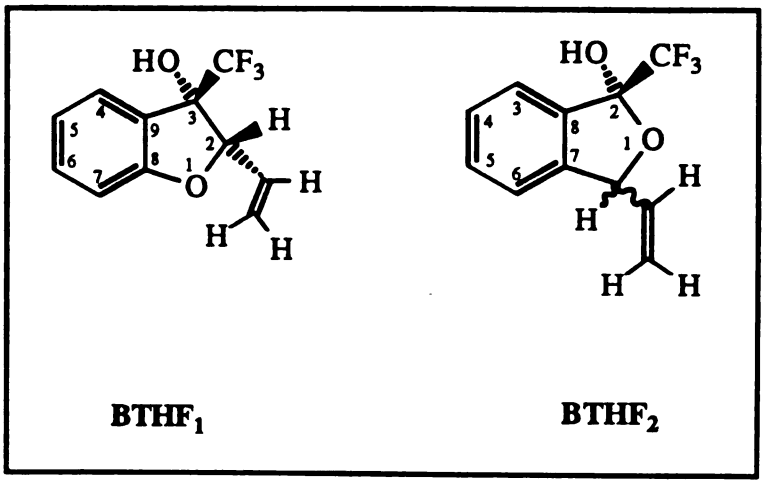


Figure 18: ^{1}H NMR spectrum of a mixture of **Z-BTHF$_1$** and **E-BTHF$_1$** obtained by irradiation of **o-PTFAc** in benzene-d_6/pyridine-d_5 followed by removal of pyridine.

Z-BTHF1 was found to have ^1H NMR spectrum similar to that of 3-phenyl-2-vinyl-2,3-dihydro-3-benzofuranol (**Ph-BTHF**) obtained by photolysis of o-allyloxy benzophenone in benzene-d_6.[94] Partial spectrum of **Z-BTHF1** shows a doublet of triplets (J = 6.58 and 1.24 Hz) at 4.99 ppm (H_2), doublet of triplets (J = 10.7 and 1.34 Hz) at 5.02 ppm (H_{14}), doublet of triplets (J = 17.28 and 1.44 Hz) at 5.23 ppm (H_{13}), doublet of doublets of doublets (J = 17.27, 10.69 and 6.58 Hz) at 5.59 ppm (H_{12}) and doublet of triplets (J = 8.23 and 0.72 Hz) at 6.71 ppm (H_7) whereas **Ph-BTHF** has doublet of doublets of doublets (J = 6.3, 1.2 and 1.4 Hz) at 4.85 ppm (H_2), doublet of doublets of doublets (J = 10.7, 1.9 and 1.2 Hz) at 5.13 ppm (H_{14}), doublet of doublets of doublets (J = 17.3, 2.0 and 1.4 Hz) at 5.25 ppm (H_{13}), doublet of doublets of doublets (J = 17.2, 10.8 and 6.3 Hz) at 6.02 ppm (H_{12}) and doublet of triplets (J = 7.41 and 1.0 Hz) at 6.72 ppm (H_7).

Previous work by Wagner and coworkers[95] showed that ortho-alkoxy-acetophenones react photochemically to give products with structures similar to that of **BTHF2** as the major product and **BTHF1** as the minor product. Although **Z-BTHF1** structure is in agreement with the ^1H NMR data, **BTHF2** is also expected to show a similar spectrum.



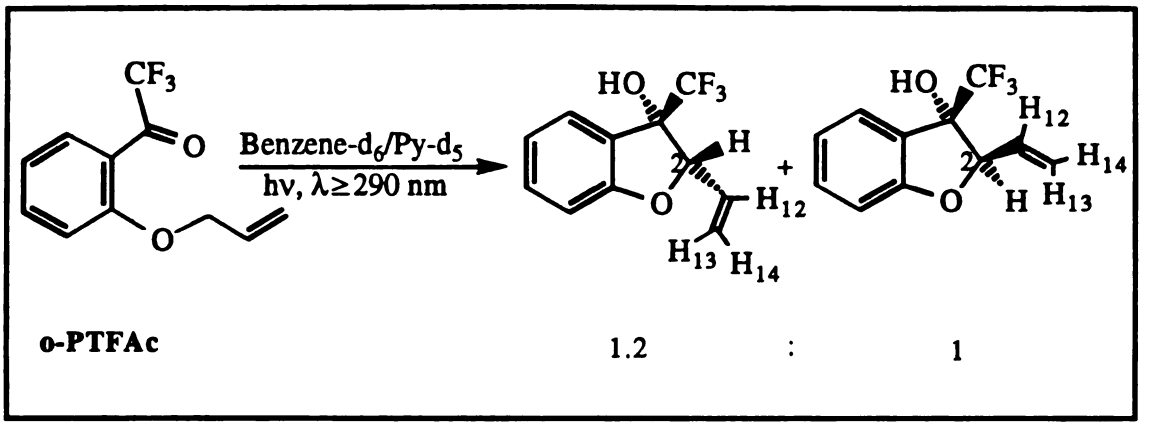
BTHF1 **BTHF2**

Scheme 99

Differentiation between the two compounds was based on ^{13}C NMR spectrum. The chemical shifts were calculated for two model compounds: *o*-methoxy benzylalcohol and *o*-xylene-α,α'-diol. Calculation was based on assuming a chemical shift of 128.5 ppm for unsubstituted benzene, then adding or subtracting a constant that correspond to the type of substituent and its position in the benzene ring.[96] The observed chemical shift was found to match those of *o*-methoxy benzyl alcohol (cf. Table 6). This suggested that **Z-BTHF$_1$** is the product formed.

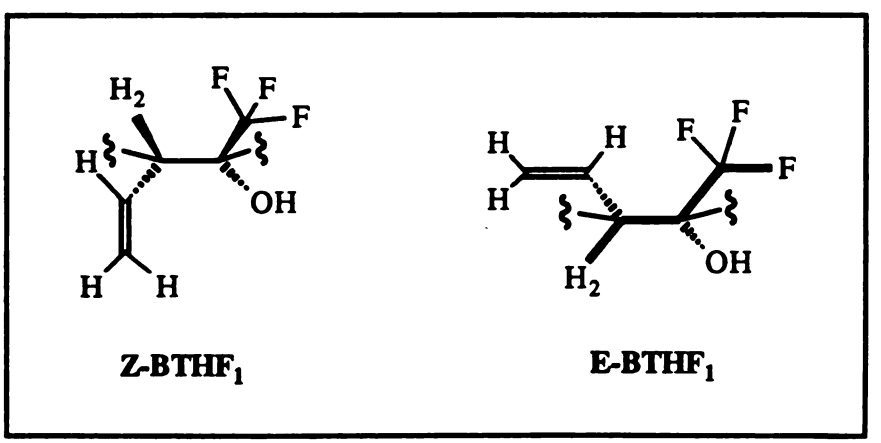
Table 6: ^{13}C NMR chemical shifts (ppm) for **Z-BTHF$_1$** and **BTHF$_2$**

Z-BTHF$_1$		**BTHF$_2$**		
C	Calculated	C	Calculated	Observed
4	128.1	3	125.7	125.02
5	119.4	4	125.7	121.72
6	128.1	5	125.7	125.02
7	112.7	6	125.7	110.94
8	158.5	7	139.4	160.08
9	126.4	8	139.4	123.38



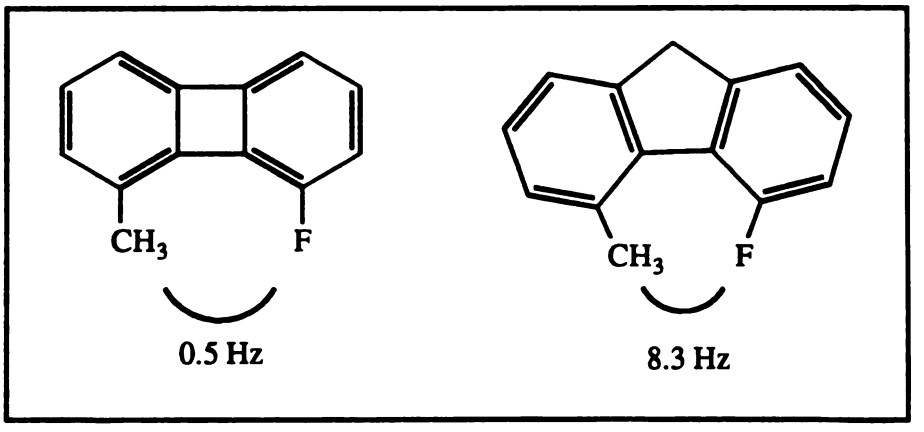
Scheme 100

In order to increase the yield of the minor product, irradiation was performed in presence of pyridine. Thus, two drops of pyridine-d5 was added to a solution of **o-PTFAc** in benzene-d_6 and irradiated using Pyrex filtered light. ^{1}H NMR showed the formation of **Z-BTHF1** and **E-BTHF1** with a ratio of 1.2 : 1 (^{1}H NMR integration). It was noticed that pyridine acted as a shift reagent since almost all of signals were shifted from their positions in the absence of pyridine. In order to resolve the spectra of the two isomers, solvent was removed under vacuum and the NMR was taken again in benzene-d_6, also the ^{1}H NMR spectra of isolated **Z-BTHF1** was taken in the same mixture of benzene-d_6/pyridine-d_5

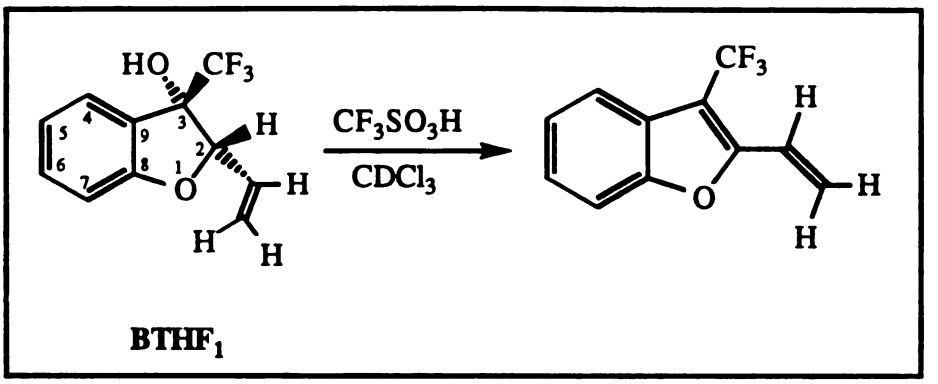


Scheme 101

The two isomers were found to have almost the same chemical shifts and coupling constants for most of their protons. The major difference was in the coupling constants for H_2 and H_{12}. For **Z-BTHF1**, H_2 is doublet of triplets with a *J* value of 6.58 and 1.24 Hz; H_{12} is doublet of doublets of doublets (*J* = 17.27, 10.69 and 6.58 Hz). For **E-BTHF1**; H_2 is a doublet of sixtets (*J* = 7.26 and 1.26 Hz) whereas H_{12} is doublet of doublets of doublets of sixtets (*J* = 17.2, 10.34, 7.35 and 2.38 Hz). In case of **E-BTHF1** H_2 has an extra coupling which is attributed to the long range W-coupling with the fluorine atoms. The anti configuration between H_2 and the CF_3 group allowed the W-configuration to occur. This configuration cannot occur for the *Z*-isomer. The extra coupling for H_{12} is due to through-space interaction between H_{12} and the CF_3 group (Scheme 101). Again the *E*-configuration allowed H_{12} to be close to the CF_3 group. This type of coupling is reported in other systems (Scheme 102).[97]



Scheme 102



BTHF$_1$

Scheme 103

BTHF$_1$ was found to be relatively stable to weak acids since it did not dehydrate on silica gel column. Also a sample of the compound in chloroform-*d* was treated with two drops of trifluoroacetic acid. ^{1}H NMR analysis showed no reaction. When two drops of trifluoromethane sulfonic acid were added, ^{1}H NMR showed the disappearance of **BTHF$_1$** with the formation of its dehydration product ; 3-trifluoromethyl-2-vinyl-benzofuran.

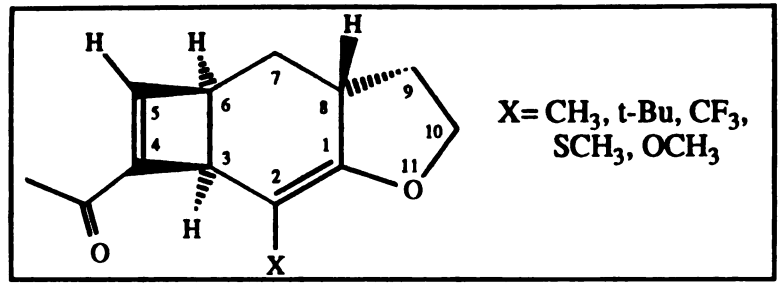
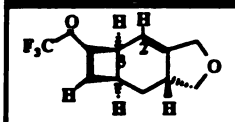
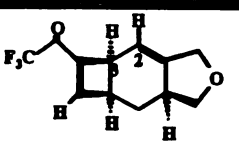
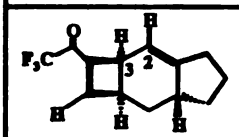
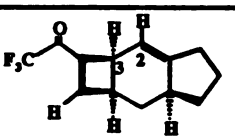
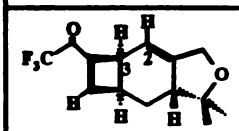
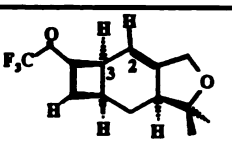
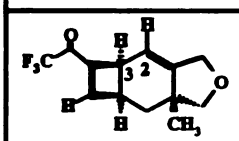
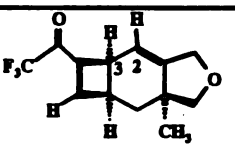
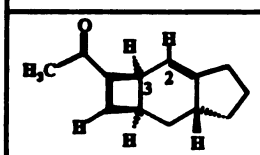
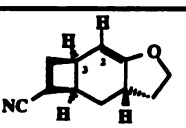
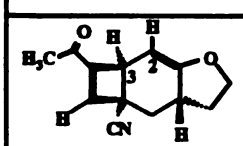
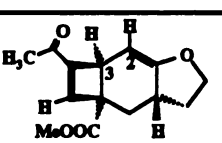


Table7: ^{1}H NMR data for some subtituted linear cyclobutenes (**LCB$_{a,anti}$**)

	SCH3		*t*-Bu		CF3		CH3		OCH3	
H	ppm	J	ppm	J	ppm	J	ppm	J	ppm	J
3	3.71	4.3, 1.0	3.82	4.2, 0.88	3.77	4.39	3.38	4.1, 0.75	3.61	4.4, 1.25
5	6.08	1.35	5.97	1.3	5.91	1.37	6.03	1.3	6.14	1.37
6	2.62	5.9, 4.4, 1.5, 1.4	2.67	5.96, 4.3, 1.55, 1.55	2.53	6.06, 4.39, 1.43, 1.43	2.66	5.97, 4.2, 1.4, 1.4	2.67	5.98, 4.43, 1.47,1.47
7	0.73	12.9, 11.8, 6.0	0.85	12.4, 11.9, 6.2	0.55	12.8, 11.9, 6.0	0.86	12.8, 11.6, 6.0	0.72	13.0, 11.6, 6.1
7	1.60	12.9, 5.2, 1.6	1.74	12.5, 4.9, 1.55	1.44	12.8, 5.2, 1.55	1.78	12.9, 5.20, 2.0	1.60	13.0, 5.0, 1.65
8	1.93	m	2.02	m	1.8	m	1.92	m	1.85	m
9	1.09	11.82, 11.82, 11.03, 8.53	1.18	11.70, 11.70, 11.05, 8.62	0.88	11.88, 11.88, 11.27, 8.66	1.21	11.57, 11.57, 11.41,8.39	1.15	11.51, 11.51 11.05, 8.63
9	1.42	11.87, 7.86, 5.63, 1.0	1.53	11.71, 7.74, 5.53, 1.1	1.23	m	1.55	11.56, 7.41, 5.43, 0.95	1.45	m
10	3.44	11.8, 8.6, 5.6	3.47	11.7, 8.6, 5.7	3.28	11.7, 8.8, 5.8	3.52	m	3.48	11.8, 8.5, 5.5
10	3.75	8.6, 8.5, 1.0	3.77	8.2, 8.2, 1.11	3.65	8.8, 8.8, 1.0	3.81	8.2, 8.2, 0.55	3.79	8.5, 8.5, 1.1
Ac	1.97	s	1.81	s	1.88	s	1.72	s	1.95	s

Table 8: $J_{2,3}$ Coupling Constants for Some **LCBs**

Compound	$J_{2,3}$ (Hz)	Ref.	Compound	$J_{2,3}$ (Hz)	Ref.
	5.7	85		2.24	85
	5.04	85		2.25	85
	5.59	85		2.23	85
	5.86	28		2.24	28
	4.9	84		6.3	83
	6.5	This work		6.7	This work

Computational Studies

a-Conformational Analysis

Photoproduct structures were optimized at the semi-empirical level (AM). From the dihedral angles, vicinal coupling constants were calculated by the Karplus equation. The best geometry and dihedral angles of various photoproducts and their coupling constants are shown in the following pages.

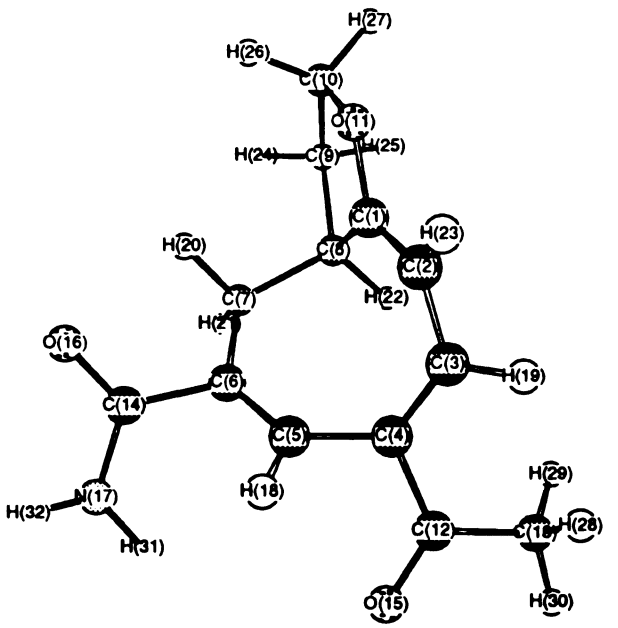


Figure 19: Best Geometry of **m-Amide-COT$_S$**

Table 9: Coupling Constants of **m-Amide-COT$_S$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{23}-C_2-C_3-H_{19}	-50.235	3.18	8.51
H_{20}-C_7-C_8-H_{22}	-169.681	8.9	7.9
H_{21}-C_7-C_8-H_{22}	-54.586	2.55	0.0
H_{22}-C_8-C_9-H_{24}	103.770	0.24	m
H_{22}-C_8-C_9-H_{25}	-16.651	7.5	11.6
H_{24}-C_9-C_{10}-H_{26}	17.797	7.41	5.7
H_{24}-C_9-C_{10}-H_{27}	-108.183	0.63	2.5
H_{25}-C_9-C_{10}-H_{26}	138.050	4.95	10.2
H_{25}-C_9-C_{10}-H_{27}	12.070	7.83	8.15

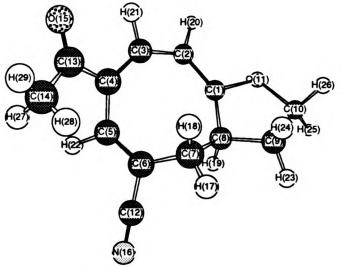


Figure 20: Best Geometry of **m-CN-COT$_S$**

Table 10: Coupling Constants of **m-CN-COT$_S$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
$H20\text{-}C_2\text{-}C_3\text{-}H_{21}$	-26.800	6.47	8.23
$H_{17}\text{-}C_7\text{-}C_8\text{-}H_{19}$	75.075	0.27	2.98
$H_{18}\text{-}C_7\text{-}C_8\text{-}H_{19}$	-167.262	8.74	8.74
$H_{19}\text{-}C_8\text{-}C_9\text{-}H_{23}$	-38.698	4.88	7.3
$H_{19}\text{-}C_8\text{-}C_9\text{-}H_{24}$	-159.730	8.06	9.26
$H_{23}\text{-}C_9\text{-}C_{10}\text{-}H_{25}$	21.016	7.11	6.5
$H_{23}\text{-}C_9\text{-}C_{10}\text{-}H_{26}$	-105.184	0.35	4.3
$H_{24}\text{-}C_9\text{-}C_{10}\text{-}H_{25}$	142.491	5.68	7.61
$H_{24}\text{-}C_9\text{-}C_{10}\text{-}H_{26}$	16.289	7.53	8.59

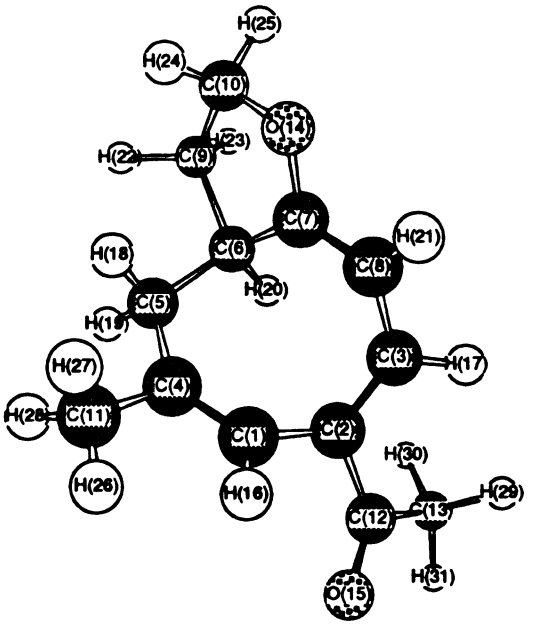


Figure 21: Best Geometry of **m-Me-COTs**

Table 11: Coupling Constants of **m-Me-COTs**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{17}-C_3-C_8-H_{21}	-51.513	2.99	8.2
H_{18}-C_5-C_6-H_{20}	-169.696	9.0	9.58
H_{19}-C_5-C_6-H_{20}	-54.584	2.55	2.54
H20-C_6-C_9-H_{22}	104.205	0.27	6.6
H20-C_6-C_9-H_{23}	-16.209	7.54	9.0
H_{22}-C_9-C_{10}-H_{24}	16.197	7.54	6.6
H_{22}-C_9-C_{10}-H_{25}	-109.353	0.75	4.0
H_{23}-C_9-C_{10}-H_{24}	136.483	4.7	7.7
H_{23}-C_9-C_{10}-H_{25}	10.935	7.89	8.64

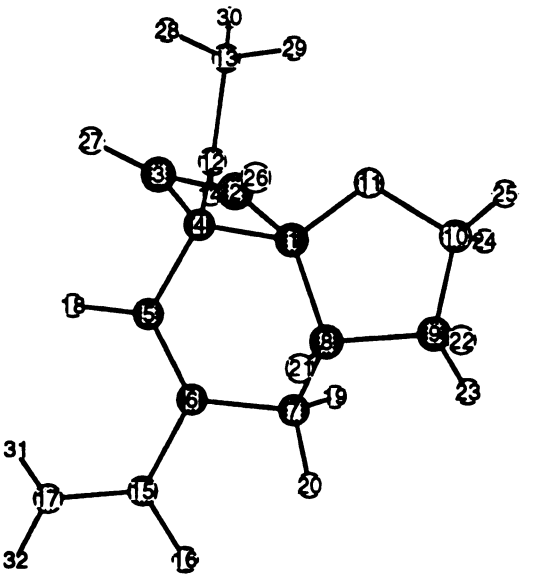


Figure 22: Best Geometry of **m-Amide-ACB$_S$**

Table 12: Coupling Constants of **m-Amide-ACB$_S$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{19}-C_7-C_8-H_{21}	-164.816	8.55	5.7
H_{20}-C_7-C_8-H_{21}	-47.918	3.52	3.0
H_{21}-C_8-C_9-H_{22}	-12.719	7.8	11.9
H_{21}-C_8-C_9-H_{23}	107.358	0.54	6.9
H_{22}-C_9-C_{10}-H_{24}	134.300	4.34	9.9
H_{22}-C_9-C_{10}-H_{25}	9.669	7.95	8.8
H_{23}-C_9-C_{10}-H_{24}	14.612	7.66	6.9
H_{23}-C_9-C_{10}-H_{25}	-110.016	0.81	2.54

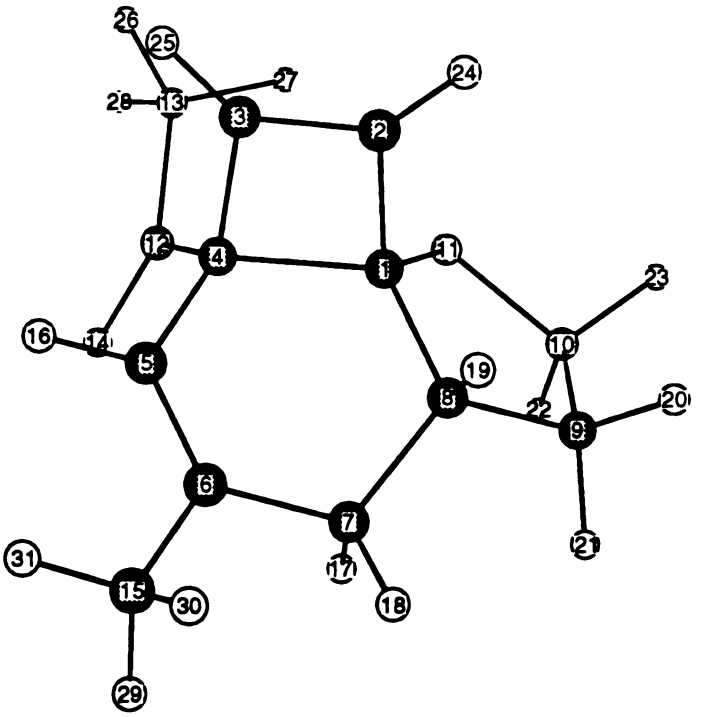


Figure 23: Best Geometry of **m-Me-ACB$_S$**

Table 13: Coupling Constants of **m-Me-ACB$_S$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{19}-C_8-C_9-H_{21}	108.751	0.7	6.7
H_{20}-C_9-C_{10}-H_{22}	132.068	3.95	6.7
H_{20}-C_9-C_{10}-H_{23}	7.798	8.04	8.8
H_{21}-C_9-C_{10}-H_{22}	12.294	7.81	6.8
H_{21}-C_9-C_{10}-H_{23}	-111.976	1.03	2.88

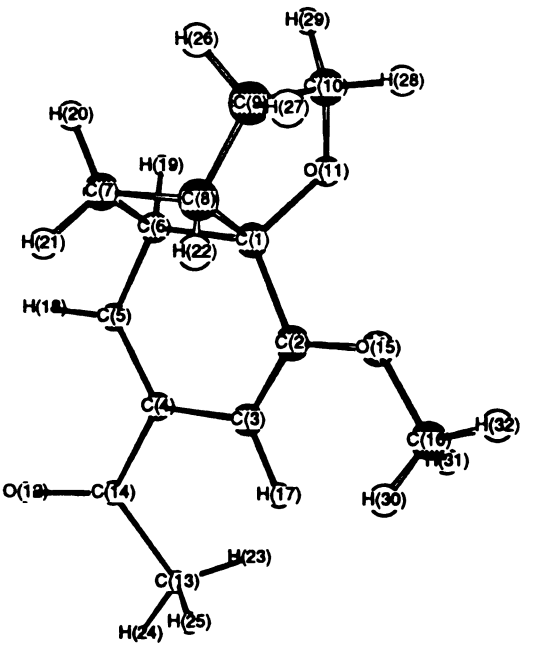


Figure 24: Best Geometry of **m-OMe-CHD$_a$**

Table 14: Coupling Constants of **m-OMe-CHD$_a$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{18}-C_5-C_6-H_{19}	-53.432	2.71	5.86
H_{19}-C_6-C_7-H_{20}	7.277	8.06	10.5
H_{19}-C_6-C_7-H_{21}	133.469	4.2	8.64
H_{20}-C_7-C_8-H_{22}	123.047	2.52	3.81
H_{21}-C_7-C_8-H_{22}	-4.029	8.16	8.64
H_{22}-C_8-C_9-H_{26}	-109.197	0.73	2.65
H_{22}-C_8-C_9-H_{27}	10.736	7.9	18.74
H_{26}-C_9-C_{10}-H_{28}	116.747	1.62	3.7
H_{26}-C_9-C_{10}-H_{29}	-7.312	8.06	9.05
H_{27}-C_9-C_{10}-H_{28}	-2.649	8.18	7.8
H_{27}-C_9-C_{10}-H_{29}	-126.712	3.09	6.12

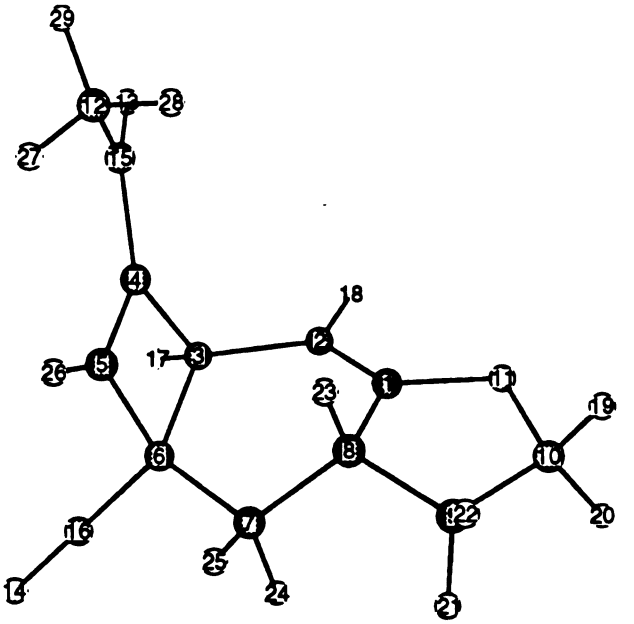


Figure 25: Best Geometry of **m-CN-LCB$_{s,anti}$**

Table 15: Coupling Constants of **m-CN-LCB$_{s,anti}$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{18}-C_2-C_3-H_{17}	30.753	5.98	6.5
H_{21}-C_9-C_{10}-H_{19}	-132.951	4.11	11.7
H_{22}-C_9-C_{10}-H_{19}	-12.908	7.78	5.67
H_{21}-C_9-C_{10}-H_{20}	-7.662	8.05	8.63
H_{22}-C_9-C_{10}-H_{20}	112.385	1.08	0.8
H_{23}-C_8-C_9-H_{21}	139.746	5.23	11.11
H_{23}-C_8-C_9-H_{22}	19.176	7.28	7.9
H_{24}-C_7-C_8-H_{23}	-169.247	8.87	11.9
H_{25}-C_7-C_8-H_{23}	-51.559	2.98	5.2

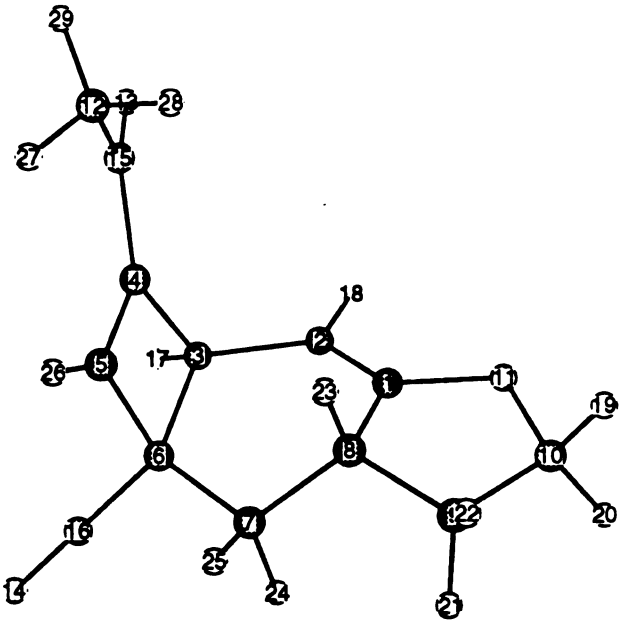


Figure 25: Best Geometry of **m-CN-LCB$_{s,anti}$**

Table 15: Coupling Constants of **m-CN-LCB$_{s,anti}$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{18}-C_2-C_3-H_{17}	30.753	5.98	6.5
H_{21}-C_9-C_{10}-H_{19}	-132.951	4.11	11.7
H_{22}-C_9-C_{10}-H_{19}	-12.908	7.78	5.67
H_{21}-C_9-C_{10}-H_{20}	-7.662	8.05	8.63
H_{22}-C_9-C_{10}-H_{20}	112.385	1.08	0.8
H_{23}-C_8-C_9-H_{21}	139.746	5.23	11.11
H_{23}-C_8-C_9-H_{22}	19.176	7.28	7.9
H_{24}-C_7-C_8-H_{23}	-169.247	8.87	11.9
H_{25}-C_7-C_8-H_{23}	-51.559	2.98	5.2

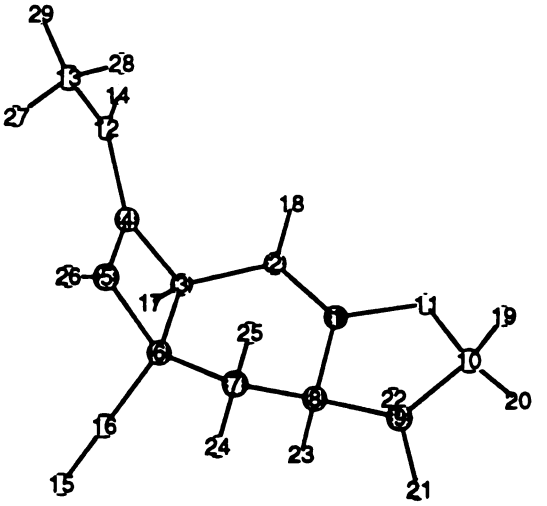


Figure 26: Best Geometry of **m-CN-LCB$_{s,syn}$** (Not Formed)

Table 16: Coupling Constants of **m-CN-LCB$_{s,syn}$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{17}-C_3-C_2-H_{18}	68.360	0.85	6.5
H_{19}-C_{10}-C_9-H_{21}	-115.139	1.4	0.8
H_{19}-C_{10}-C_9-H_{22}	4.947	8.1	8.63
H_{20}-C_{10}-C_9-H_{21}	10.147	7.9	11.7
H_{20}-C_{10}-C_9-H_{22}	130.225	3.7	5.67
H_{21}-C_9-C_8-H_{23}	-18.653	7.3	11.11
H_{22}-C_9-C_8-H_{23}	-139.085	5.1	7.9
H_{23}-C_8-C_7-H_{24}	56.320	2.4	5.2
H_{23}-C_8-C_7-H_{25}	174.925	9.1	11.9

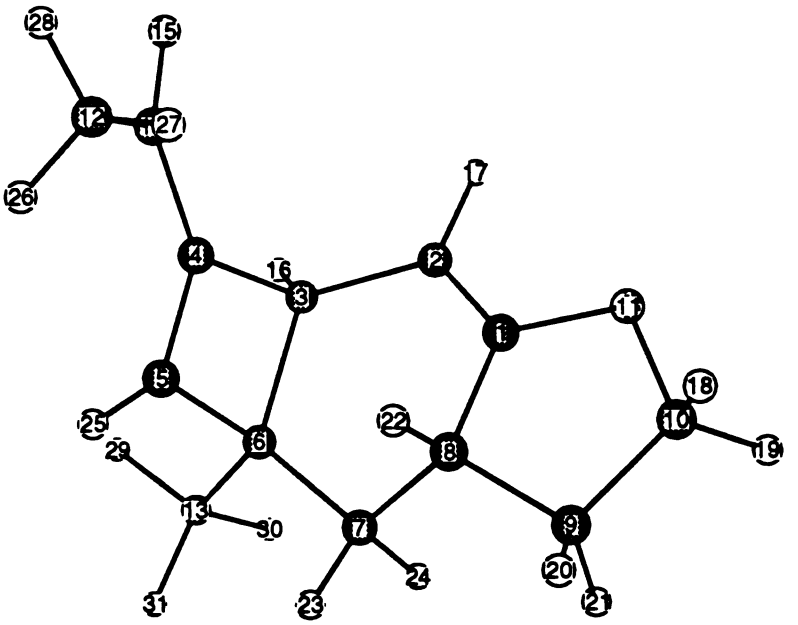


Figure 27: Best Geometry of **m-Me-LCB$_{s,anti}$**

Table 17: Coupling Constants of **m-Me-LCB$_{s,anti}$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{16}-C_3-C_2-H_{17}	32.285	5.8	6.35
H_{18}-C_{10}-C_9-H_{20}	-17.859	7.4	8.7
H_{18}-C_{10}-C_9-H_{21}	-138.134	4.95	5.55
H_{19}-C_{10}-C_9-H_{20}	107.475	0.5	0.8
H_{19}-C_{10}-C_9-H_{21}	-12.797	7.78	8.8

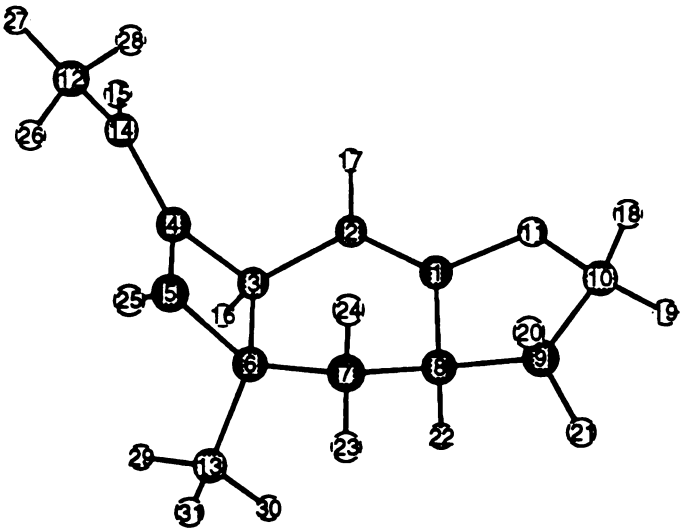


Figure 28: Best Geometry of **m-Me-LCB$_{s,syn}$** (Not Formed)

Table 18: Coupling Constants of **m-Me-LCB$_{s,syn}$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{17}-C_2-C_3-H_{16}	69.205	0.77	6.35
H_{20}-C_9-C_{10}-H_{18}	6.206	8.1	8.7
H_{21}-C_9-C_{10}-H_{18}	-114.029	1.27	0.8
H_{20}-C_9-C_{10}-H_{19}	131.356	3.85	5.55
H_{21}-C_9-C_{10}-H_{19}	11.117	7.88	8.8

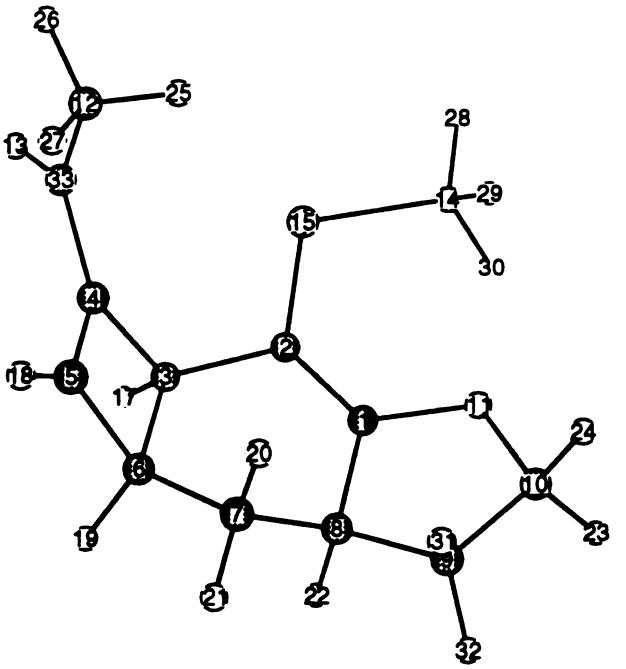


Figure 29: Best Geometry of **m-SMe-LCB$_{a,syn}$** (Not Formed)

Table 19: Coupling Constants of **m-SMe-LCB$_{a,syn}$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{17}-C_3-C_6-H_{19}	1.096	8.2	4.3
H_{32}-C_9-C_{10}-H_{24}	-115.251	1.44	1.0
H_{31}-C_9-C_{10}-H_{24}	4.896	8.14	8.5
H_{32}-C_9-C_{10}-H_{23}	9.935	7.95	5.6
H_{31}-C_9-C_{10}-H_{23}	130.084	3.63	11.8
H_{22}-C_8-C_9-H_{32}	-18.802	7.32	7.8
H_{22}-C_8-C_9-H_{31}	-139.356	5.18	11.03
H_{21}-C_7-C_8-H_{22}	56.313	2.32	5.16
H_{20}-C_7-C_8-H_{22}	174.076	9.1	11.76
H_{19}-C_6-C_7-H_{21}	-29.849	6.09	1.6
H_{19}-C_6-C_7-H_{20}	-148.102	6.55	5.97
H_{18}-C_5-C_6-H_{19}	69.247	0.77	1.35

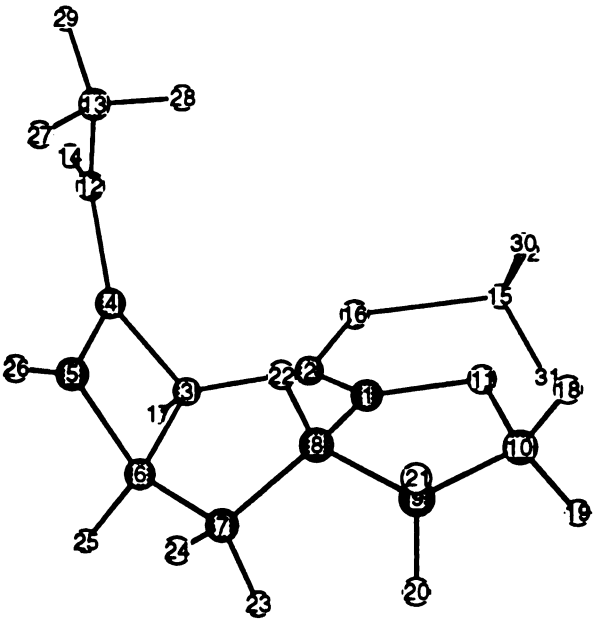


Figure 30: Best Geometry of **m-SMe-LCB$_{a,anti}$**

Table 20: Coupling Constants of **m-SMe-LCB$_{a,anti}$**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{17}-C_3-C_6-H_{25}	-0.706	8.2	4.3
H20-C_9-C_{10}-H_{18}	-128.874	3.46	11.8
H_{21}-C_9-C_{10}-H_{18}	-8.837	8.0	5.62
H20-C_9-C_{10}-H_{19}	-3.731	8.16	8.5
H_{21}-C_9-C_{10}-H_{19}	116.296	1.53	1.0
H_{22}-C_8-C_9-H_{20}	139.741	5.27	11.03
H_{22}-C_8-C_9-H_{21}	19.323	7.3	7.82
H_{23}-C_7-C_8-H_{12}	-169.228	8.85	11.76
H_{24}-C_7-C_8-H_{22}	-51.695	2.93	5.16
H_{25}-C_6-C_7-H_{23}	43.659	4.1	6.0
H_{25}-C_6-C_7-H_{24}	-73.667	0.35	1.6
H_{26}-C_5-C_6-H_{25}	69.740	0.7	1.3

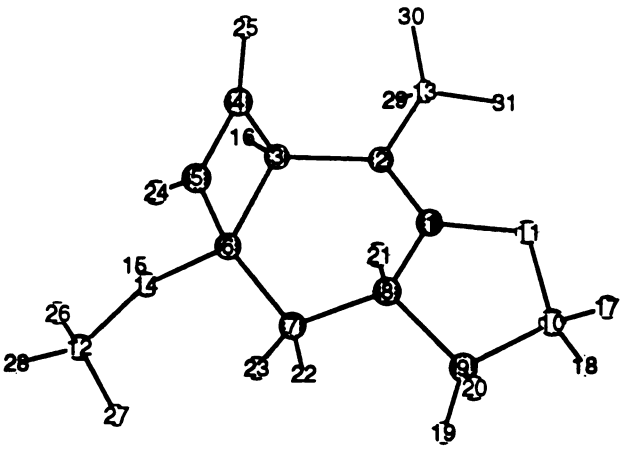


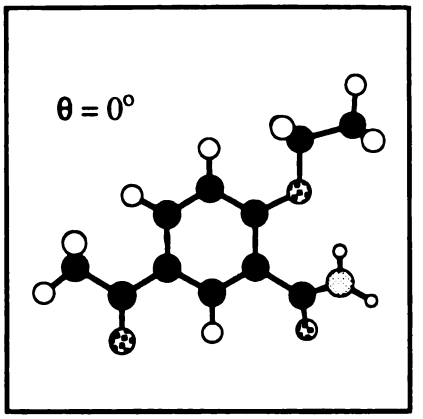
Figure 31: Best Geometry of **m-Me-o-LCB$_{s,anti}$**

Table 21: Coupling Constants of **m-Me-o-LCB**

Atoms	dihedral angle ϕ	J(calc)	J(exp)
H_{16}-C_3-C_4-H_{25}	-67.628	0.93	0.88
H_{19}-C_9-C_{10}-H_{17}	-129.758	3.59	11.65
H_{20}-C_9-C_{10}-H_{17}	-9.528	7.96	5.58
H_{19}-C_9-C_{10}-H_{18}	-5.629	8.12	8.4
H_{20}-C_9-C_{10}-H_{18}	114.600	1.35	1.0
H_{21}-C_8-C_9-H_{19}	140.900	5.42	11.34
H_{21}-C_8-C_9-H_{20}	20.024	7.2	7.6
H_{22}-C_7-C_8-H_{21}	-169.485	8.88	11.82
H_{23}-C_7-C_8-H_{21}	-52.192	2.89	5.3

b-Rotational Barriers

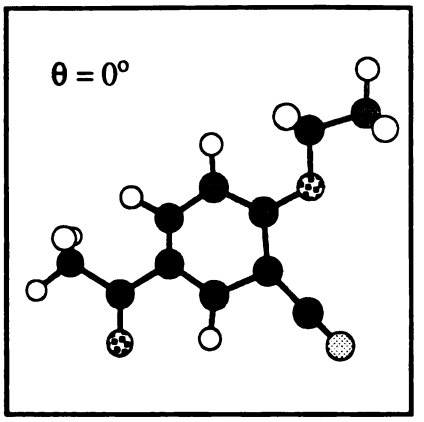
Semi-empirical calculations were carried to provide an idea of the rotational barriers around the C--O bond of the excited triplet states of the substituted alkenoxyacetophenones. Thus, various meta substituted *para*-ethoxyacetophenones were used as model compounds. The calculations were done using the semi-empirical level (AM1) and by using unrestricted Hartree-Fock (UHF) treatment.



5-acetyl-2-ethoxy benzamide

Table 22: Calculated rotational barrier around C—OEt bond for 5-acetyl-2-ethoxy benzamide excited triplet state.

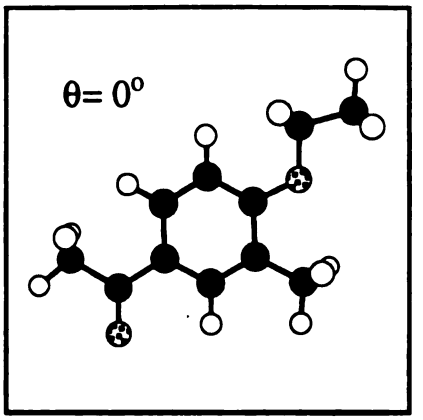
θ	ΔG(kcal/mol)
0.0	0.0
90	4.0
180	6.0



3-cyano-4-ethoxyacetophenone

Table 23: Calculated rotational barrier around C—OEt bond for 3-cyano-4-ethoxy-acetophenone excited triplet state.

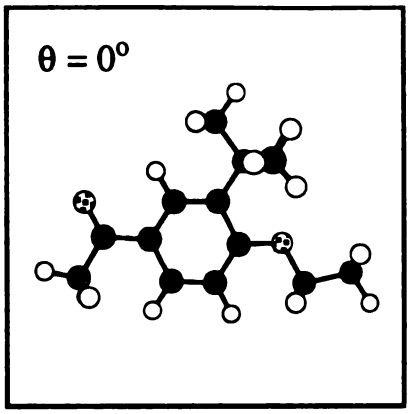
θ	ΔG(kcal/mol)
0.0	0.0
90	4.0
180	4.0



4-ethoxy 3-methylacetophenone

Table 24: Calculated rotational barrier around C—OEt bond for 4-ethoxy 3-methyl-acetophenone excited triplet state.

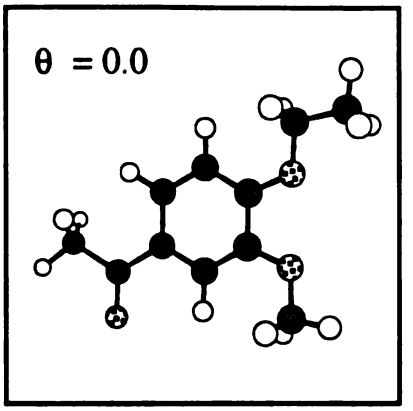
θ	ΔG(kcal/mol)
0.0	0.0
90	3.8
180	6.0



3-*t*-butyl-4-ethoxyacetophenone

Table 25: Calculated rotational barrier around C—OEt bond for 3-*t*-butyl-4-ethoxy-acetophenone excited triplet state.

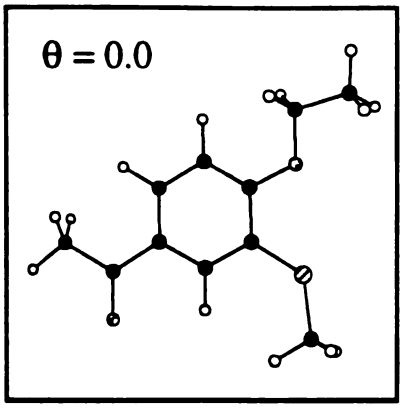
θ	ΔG(kcal/mol)
0.0	0.0
90	3.7
180	7.6



4-ethoxy-3-methoxyacetophenone

Table 26: Calculated rotational barrier around C—OEt bond for 4-ethoxy-3-methoxy-acetophenone excited triplet state.

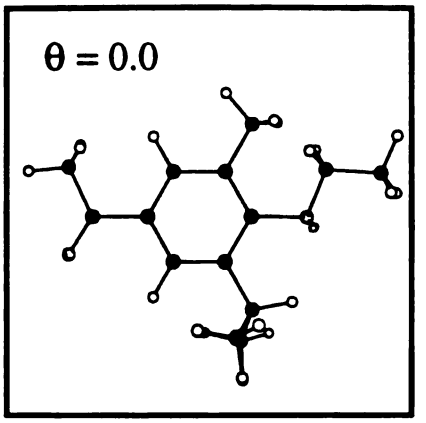
θ	ΔG(kcal/mol)
0.0	0.0
90	3.0
180	0.55



4-ethoxy-3-mercaptomethylacetophenone

Table 27: Calculated rotational barrier around C—OEt bond for 4-ethoxy-3-mercaptomethylacetophenone excited triplet state.

θ	ΔG(kcal/mol)
0.0	0.0
90	2.15
180	0.75



4-ethoxy-3-isopropyl-5-methylacetophenone

Table 28: Calculated rotational barrier around C—OEt bond for 4-ethoxy-3-isopropyl-5-methylacetophenone excited triplet state.

θ	ΔG(kcal/mol)
0.0	4.3
75	0.0
90	1.1
110	0.4
180	7.0

c-Heats of Formation

The heat of formation of some photoproducts and proposed intermediates were calculated using the semi-emperical level (AM1). Results are presented in table.29.

Table 29: Calculated Heat of Formations For Some Compounds.

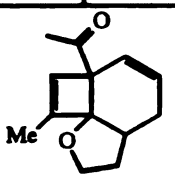
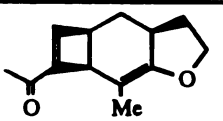
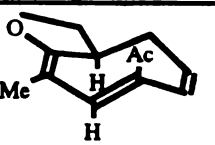
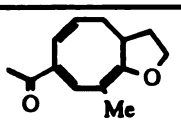
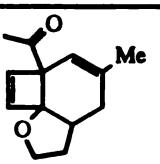
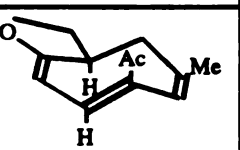
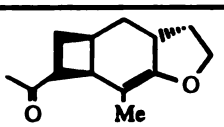
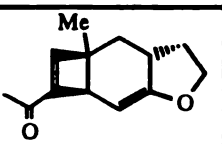
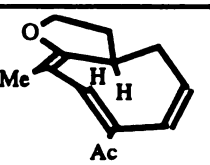
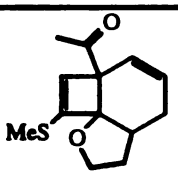
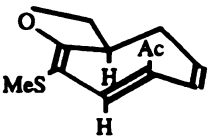
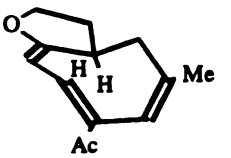
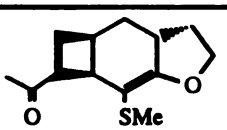
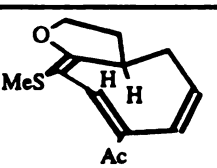
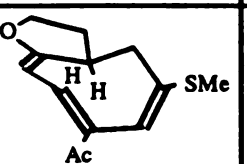
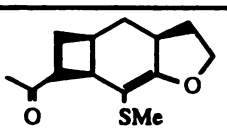
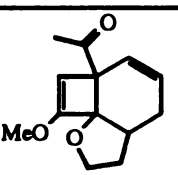
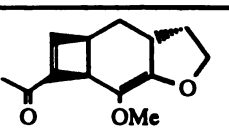
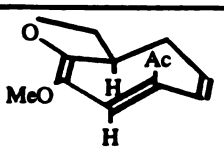
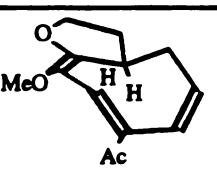
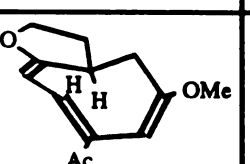
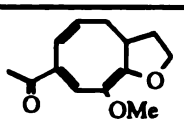
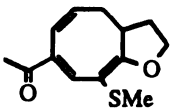
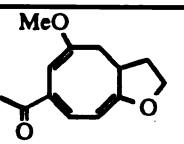
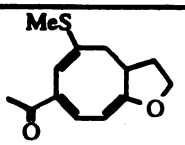
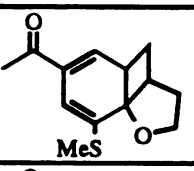
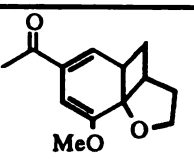
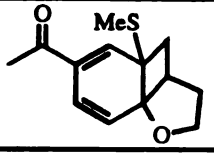
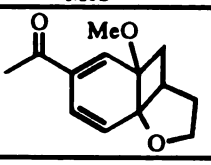
Compound	ΔH^a	Compound	ΔH^a	Compound	ΔH^a
	-17.1		-23.9		-18.2
	-40.5		-15.9		-19.0
	-24.4		-20.8		-21.0
	-12.4		-13.1		-21.5
	-16.8		-15.2		-16.2
	-16.2		-46.9		-52.6
	-46.9		-49.1		-54.6

Table 29 (cont'd)

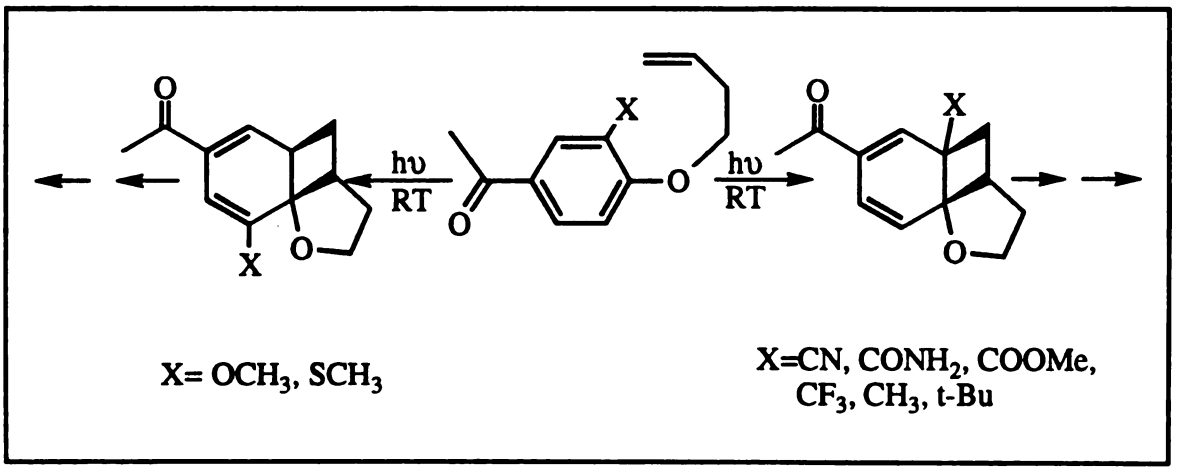
	-69.00		-34.59		-72.70
	-34.66		-34.86		-72.14
	-25.35		-67.80		

a: kcal/mol

DISCUSSION

Regioselectivity

The intramolecular [2+2] photocycloaddition of double bonds to meta substituted para-alkenoxyacetophenones showed variable regioselectivity. Generally, electron-withdrawing groups direct the double bonds to add towards them while strong electron-donating groups reverse the selectivity and direct the double bonds away (Scheme 104). The specificity induced by the electron-withdrawing groups is not surprising, as it was observed that *o*-butenoxy-acetophenones,[18] acetonaphthones,[30] and benzonitriles[98] show complete selectivity. Surprisingly, alkyl groups which are moderately electron-donating also produce high selectivity towards their direction (Scheme 104). This indicates that there is a second major factor that determines regioselectivity.



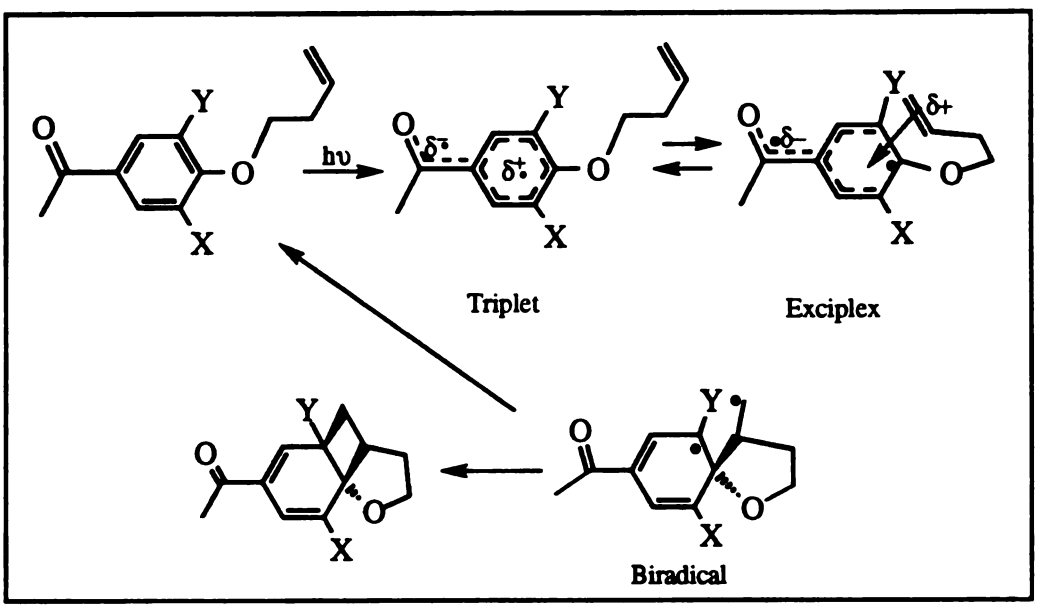
Scheme 104

In order to understand the reason for this regioselectivity, each step of the reaction mechanism must be analyzed. Both electronic and steric effects must also

be considered. Possible mechanisms for the subsequent thermal rearrangements will be discussed.

Overall Mechanism

The general picture of the overall reaction mechanism is shown in (Scheme 105).

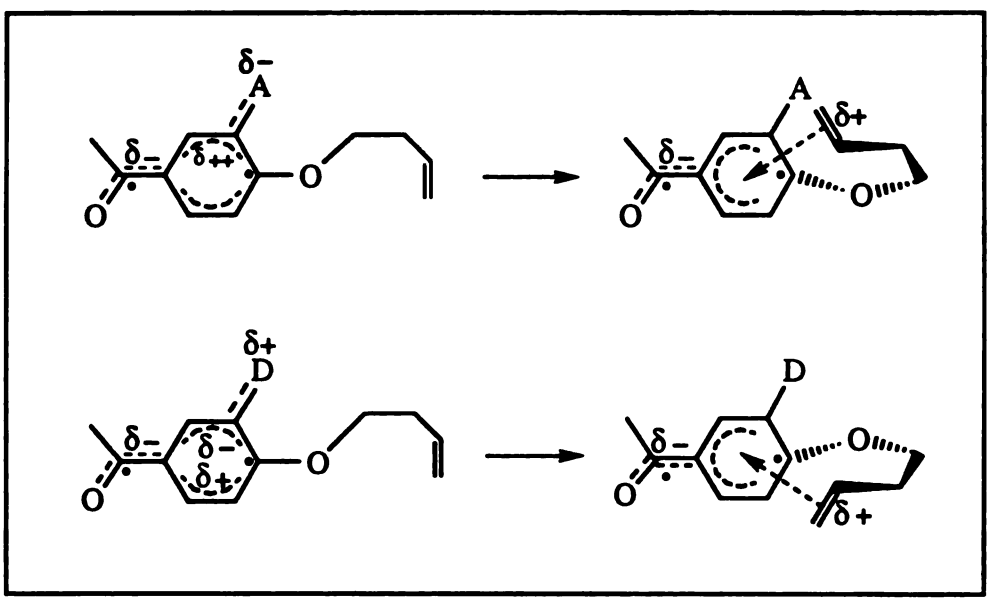


Scheme 105

Triplet-State and Exciplex Formation

The first step of the reaction is proposed to be exciplex formation between the electron-donor double bond and the electron-rich benzene ring. The approach of the double bond is affected by the charge distribution at the benzene ring. Donor ring substituents (OMe and SMe) donate electrons to the ring and cause the ring side close to the substituent to be electron richer relative to the other side, on the other hand electron-withdrawing substituents (CN,

-$CONH_2$, -COOMe and -CF_3) have the opposite effect and cause their side of the benzene ring to be more electron deficient than the other side (Scheme 106). The overall results are consistent with the donor double bond avoiding electron-rich sites on the benzene ring and being attracted to electron-deficient sites. This picture is analogous to the one originally suggested to explain regioselectivity in the photocycloaddition of enones to double bonds.[56] However, recent studies ruled out the importance of exciplexes in enone cycloadditions.[99] On the other hand, triplet decay kinetic studies support the postulated donor-acceptor

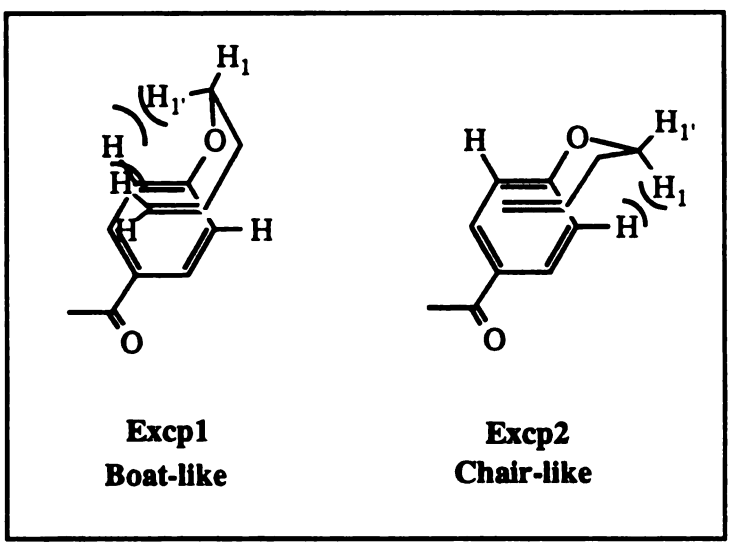


Scheme 106

behavior in our system.[23] However, the change in rate constants is much smaller than the variation in regioselectivity. Moreover, a methyl group promotes mostly syn addition, even though it slows down the reaction. This means that there is another factor that causes this selectivity.

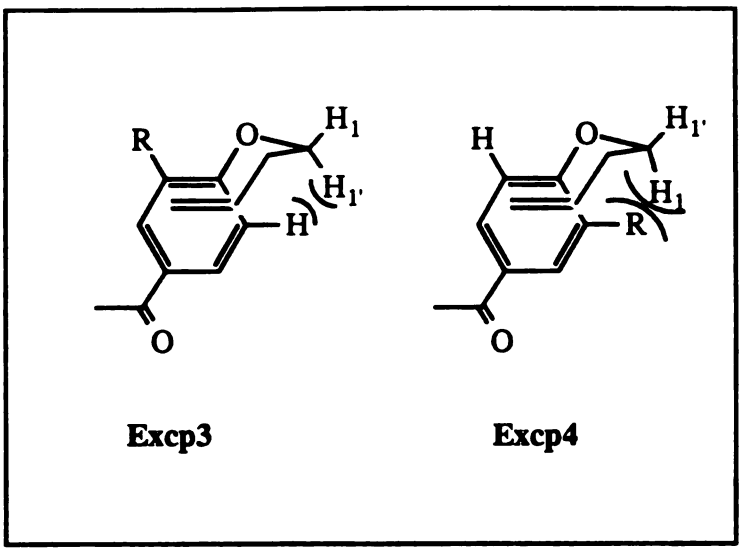
One of these possible factors is steric interactions during exciplex formation. The exciplex has the double bond and the benzene ring placed in parallel planes and separated by 2.5~3.0 Å. In the case of *p*-butenoxy-

acetophenone, this will result in the formation of two possible exciplexes. **Excp1** has cyclohexane boat-like structure and is expected to have a higher energy than **Excp2** which has a chair-like structure (Scheme 107). These two structures are similar to the transition states of the hexenyl radical cyclization proposed by Beckwith[100] and Houk.[101]



Scheme 107

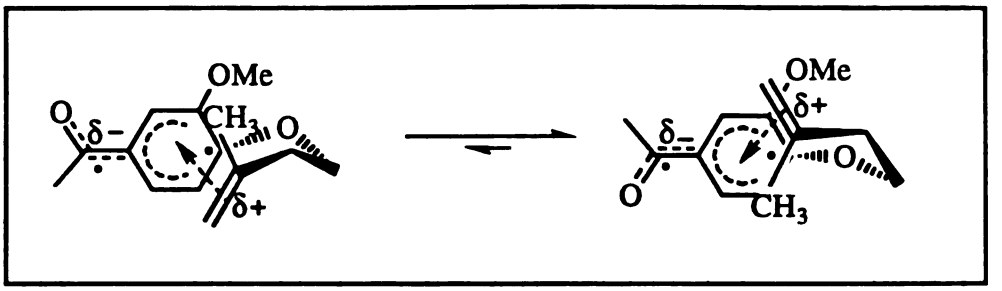
When a substituent is placed ortho to the tether, four different exciplexes could be formed. However, only the chair-like exciplexes, **Excp3** and **Excp4** will be considered because of their lower energy (Scheme 108). **Excp4** which leads to anti photocycloaddition, suffers from serious nonbonded interactions between H_1 and the substituent ortho to the tether whereas **Excp3** which leads to the syn addition has much less non bonded interactions. These interactions will always favor the addition syn to the ring substituent. In case of electron-withdrawing ring substituents, both electronic and steric effects favor the double bond



Scheme 108

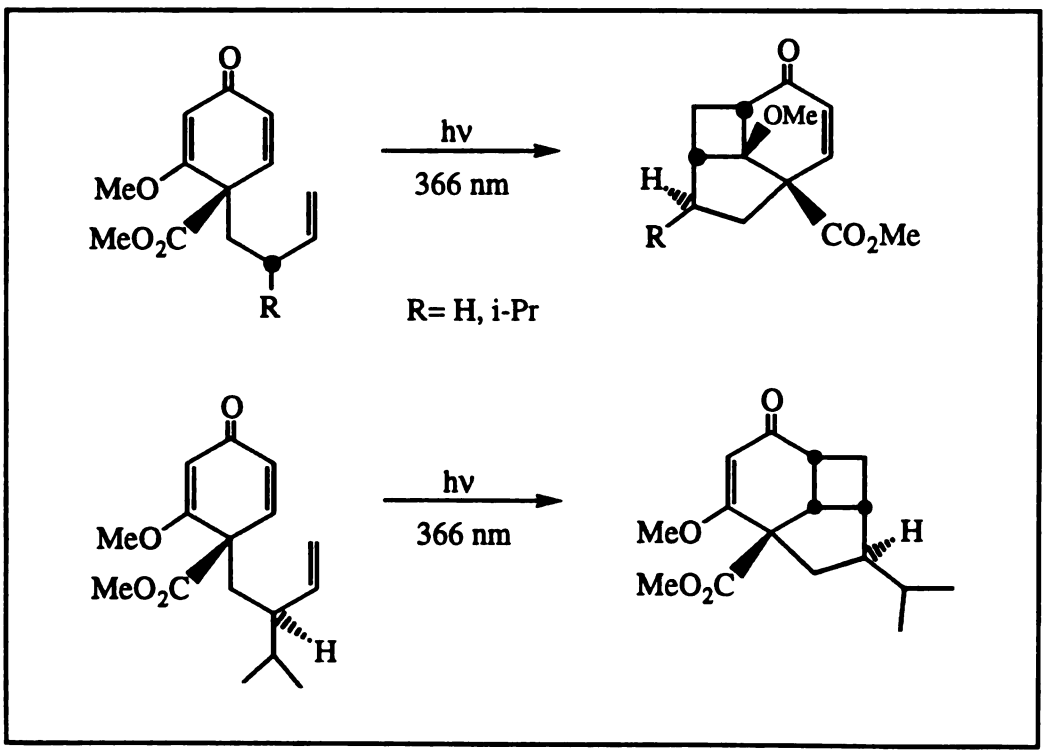
addition syn to the substituent. Experimental results showed the specificity of the reaction in such cases. With strong electron donating ring substituents (OMe, SMe), the electronic effect favors double bond addition anti to the ring substituent whereas the steric effect favors addition syn to the substituent. Experimental results showed that the syn / anti product ratio was about 1 : 6 (OMe) and 1 : 8 (SMe). This shows that electronic the effect overcomes the steric effect in these cases because of the strong electron-donating effect and relatively small size of the methoxy and thiomethoxy groups.

Alkyl ring substituents act as weak electron-donating groups, as observed by kinetics, but have a strong steric effect because of their relatively large size. At room or lower temperatures, *t*-butyl or methyl groups ortho to the tether caused the double bond to add towards them. These results show that large substituents force the double bond to add syn to them. To confirm this observation, a competitive experiment in which methyl and isopropyl groups were placed ortho to the tether showed that the double bond adds syn to the isopropyl group.



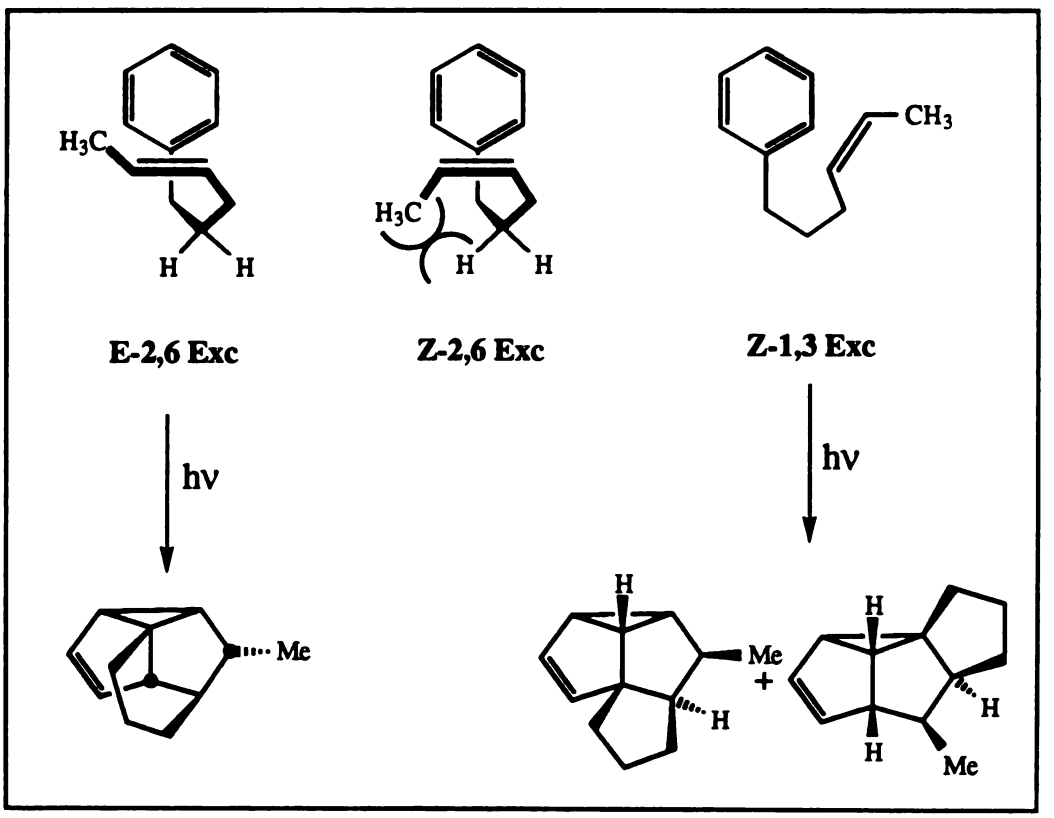
Scheme 109

Steric interactions can also suppress the anti addition of **m-OMe-pBA**. A methyl group on the internal double bond position completely reverses the regioselectivity and promotes only syn addition product. This may be a result of the non-bonded interactions between the ring methoxy group and the methyl group on the double bond, which are created during the exciplex formation (Scheme 109).



Scheme 110

This result is similar to those observed by Schultz and coworkers. They found that the intramolecular photocycloaddition of cross-conjugated cyclohexenone to double bonds is regoiselective depending on the substituents on the dienone double bonds. A methoxy group on the C_3 position of the dienone forced the olefin to add to the unsubstituted double bond. When a chiral center (isopropyl group) was placed on the butenyl side chain ($C_{2'}$), steric interactions between the carbomethoxy and isopropyl groups was found to direct [2+2] photocycloaddition to preferentially one of the two dienone double bonds (Scheme 110).[102]



Scheme 111

Selectivity is thought to be strongly influenced by steric interactions during exciplex formation in meta photocycloaddition reaction. *E*-6-phenylhex-2-ene was found to undergo meta photocycloaddition across the donor directing group (**E-2,6 Exc**). The *Z*-isomer does not exhibit the same regioselectivity due to steric destabilization during the exciplex formation. Interestingly, meta-cycloaddition is still observed but through the double bond addition to the arene carbons 1 and 3 (**Z-1,3 Exc**) (Scheme 111)

Since π,π^* triplets have radical and cationic character on the benzene ring,[12] the oxygen of *p*-alkenoxyacetophenones stabilizes the excited triplet and are partially conjugated with the benzene ring.[12] AM1 calculations for the triplet excited state of various meta- substituted *p*-ethoxyacetophenones showed that in the conformation with the lowest energy, the O—C bond of the side chain lies in the plane of the benzene ring and anti to the meta-substituent (**Anti-Triplet**). One indication of the participation of the oxygen is the existence of a barrier to rotation around the O—C bond. For most meta substituents.

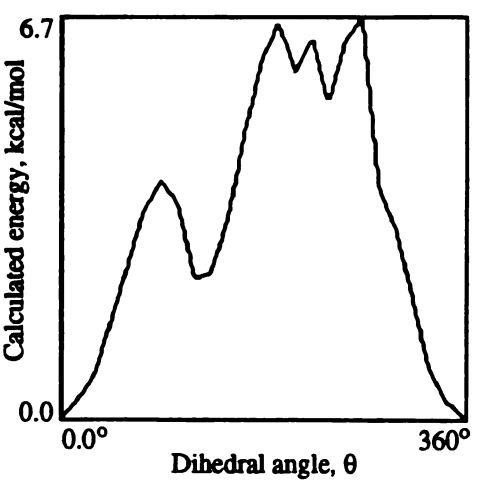


Figure 32: Dihedral drive for rotation around C—OEt bond for 5-acetyl-2-ethoxy benzamide excited triplet state.

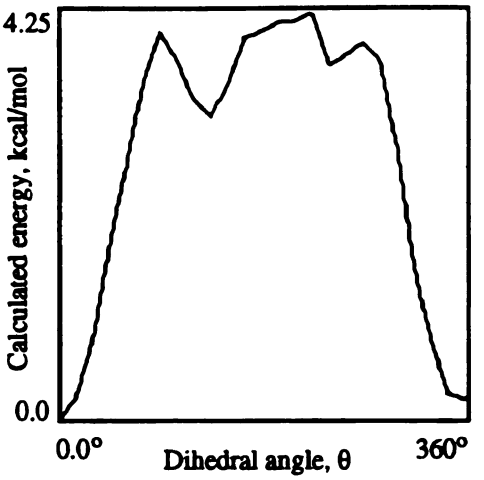


Figure 33: Dihedral drive for rotation around C—OEt bond for 3-cyano-4-ethoxy-acetophenone excited triplet state.

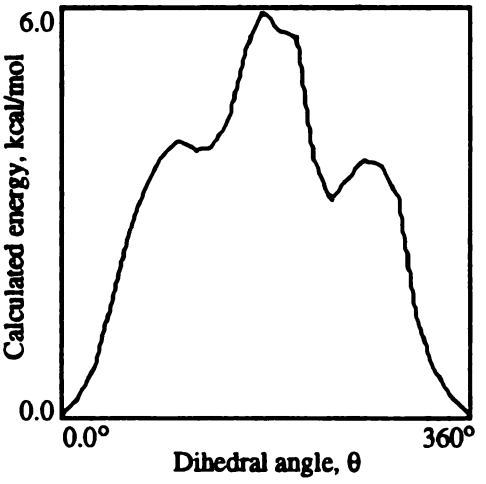


Figure 34: Dihedral drive for rotation around C—OEt bond for 4-ethoxy 3-methyl-acetophenone excited triplet state.

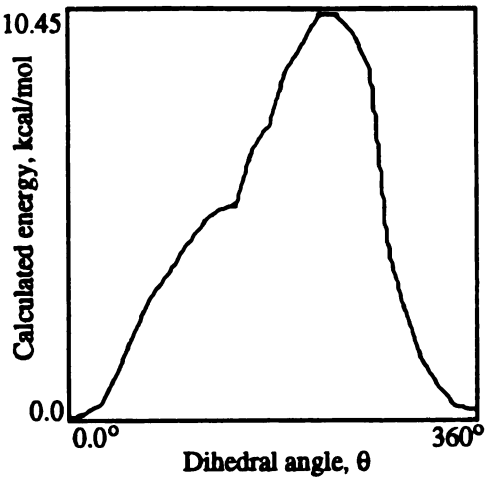


Figure 35: Dihedral drive for rotation around C—OEt bond for 3-*t*-butyl-4-ethoxy-acetophenone excited triplet state.

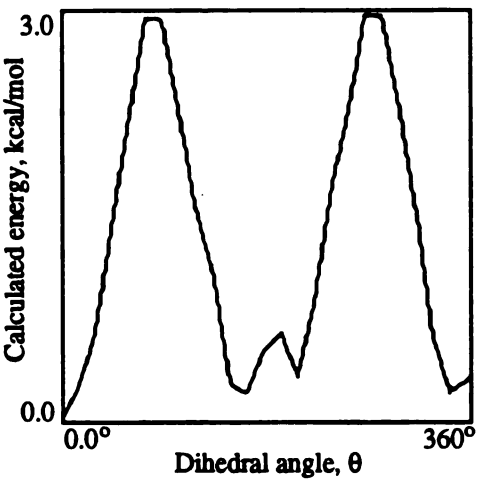


Figure 36: Dihedral drive for rotation around C—OEt bond for 4-ethoxy-3-methoxy-acetophenone excited triplet state.

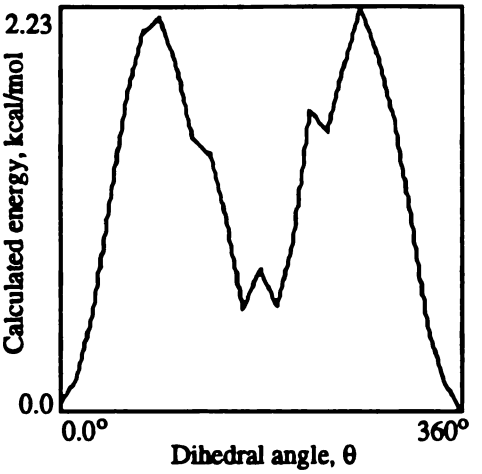


Figure 37: Dihedral drive for rotation around C—OEt bond for 4-ethoxy-3-mercaptomethylacetophenone excited triplet state.

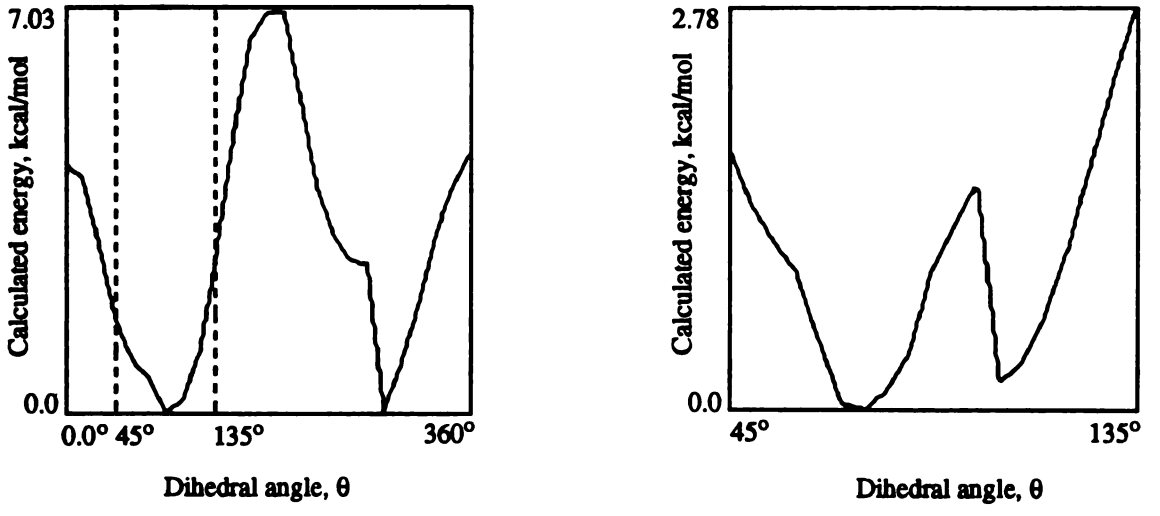
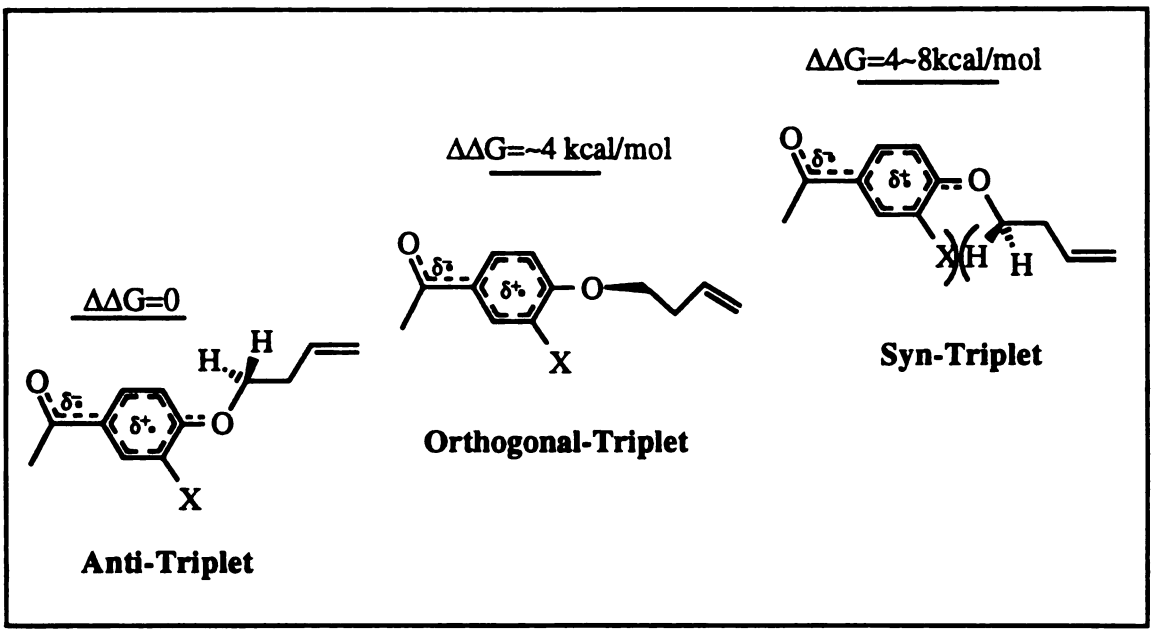


Figure 38: Dihedral drive for rotation around C—OEt bond for 4-ethoxy-3-isopropyl-5-methylacetophenone excited triplet state.

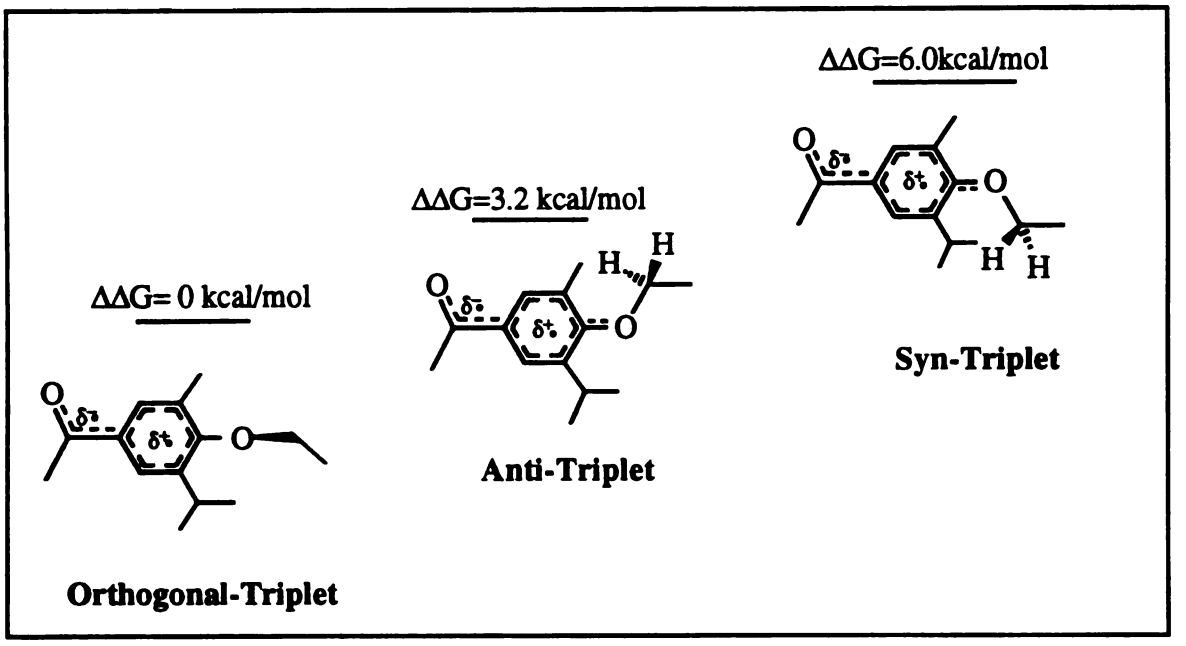
The barrier was calculated to be about 4 kcal/mol. The high energy conformation of the triplet is reached when the O—C bond is orthogonal to the plane of the benzene ring (**Orthogonal-Triplet**). Continuing rotation leads to a higher energy conformation (**Syn-Triplet**) at which the O—C bond is in the plane of the ring and syn to the meta-substituent. This conformation is about 4~8 kcal/mol higher than the **Anti-Triplet** for all substituents except methoxy and thiomethoxy, for which are only 0.55 and 0.75 kcal/mol higher in energy (Scheme 112)



Scheme 112

This means that in most cases, the **Anti-Triplet** is the major contributor to the triplet ketones. This should affect the pathway by which the side chain and the double bond reach on top of the benzene ring to form the exciplex. However, this may not be a key contributor to the observed regioselectivity. AM1 calculation showed that for 3-isopropyl-4-methoxy-5-methylacetophenone,,

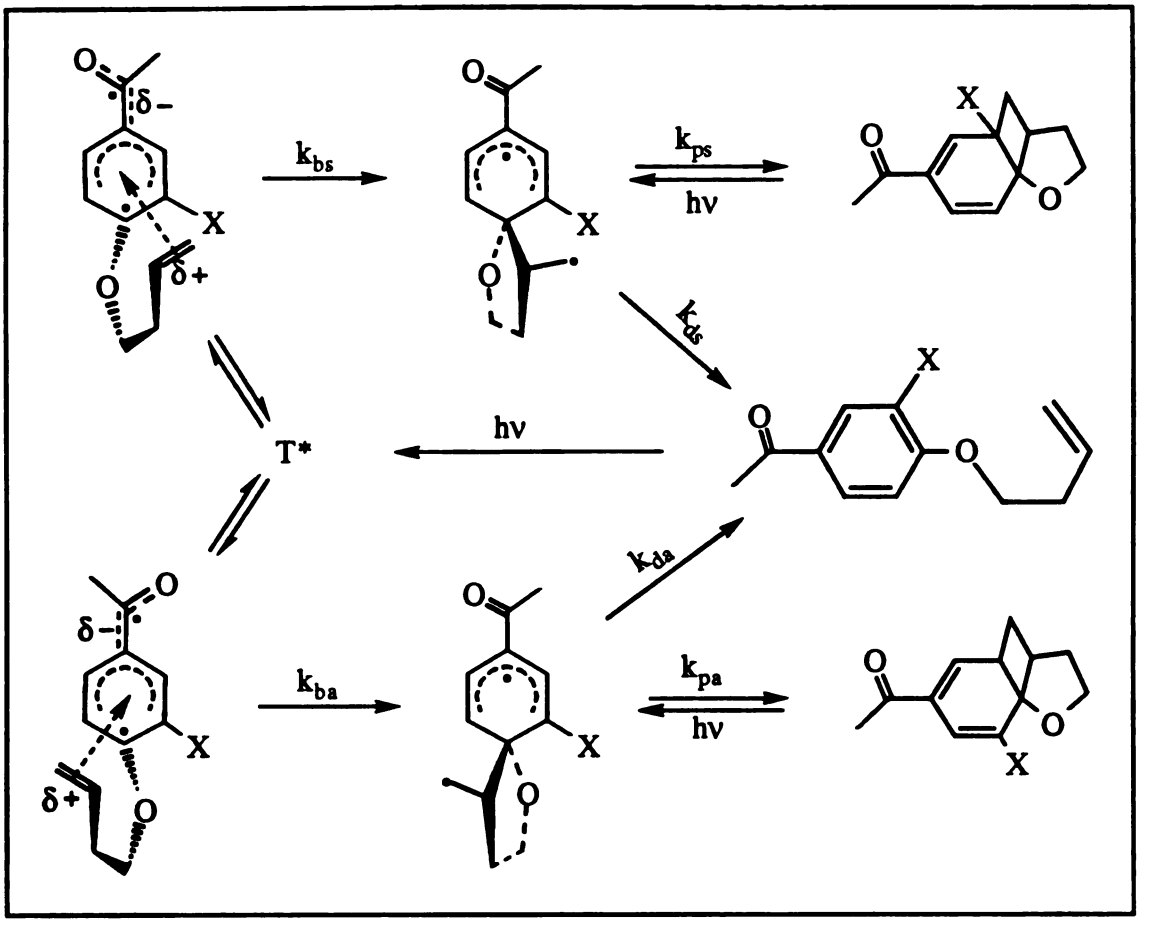
the **Orthogonal-Triplet** is about 3.2 and 6.0 kcal/mol lower in energy than **Anti-Triplet** and **Syn-Triplet** respectively (Scheme 113). In such a case the double bond is free to add either way. Experimental results shows that the double bond adds exclusively towards the isopropyl group.



Scheme 113

Radical Addition

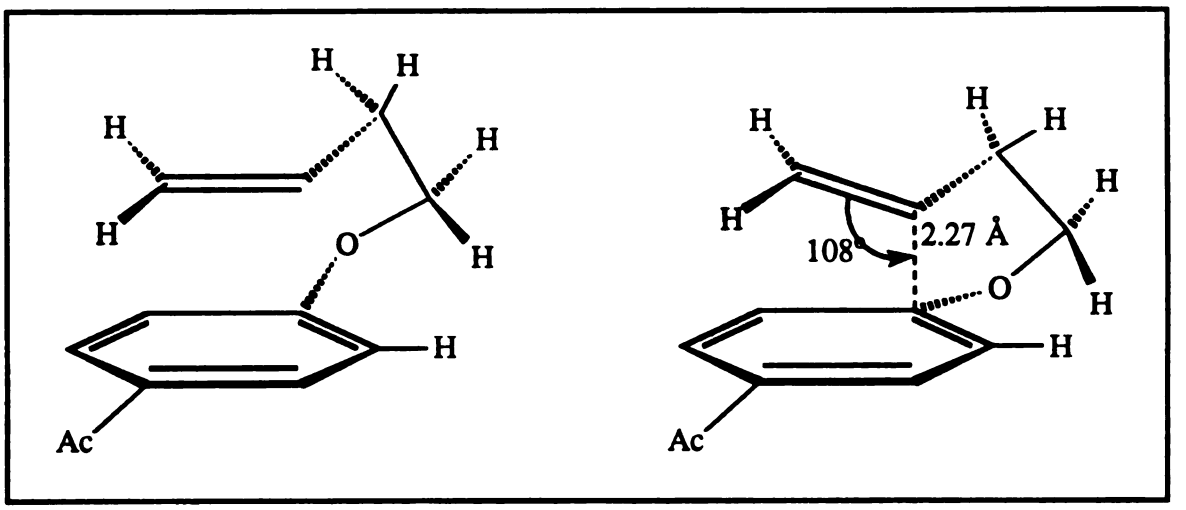
Syn and anti exciplexes can either collapse to form syn and anti biradicals, undergo reversible dissociation to the triplet state or undergo irreversible radiationless decay to the ground state (Scheme 114). The efficient cis-trans isomerization of the double bond observed by Wagner and Nahm demands high efficiency for biradical formation.[17] This means that radiationless decay may not be a significant factor in regioselectivity.



Scheme 114

Following exciplex formation, the radical center para to the acetyl group will add to the internal double bond position forming a 1,4 biradical. Theoretical treatment of the hexenyl radical transition state predicted that the C—C bond being formed has a bond distance of about 2.27 Å and the angle between the double bond plane and the incipient bond of about 108°.[101] Applying these results to our system suggested that the transition state for the radical addition reaction is similar in structure to the exciplex with some minor differences; the distance between the ring carbon and the internal double bond carbon becomes about 2.27 Å and the external double bond carbon moves away from the plane of the benzene ring to reach the 108° proposed angle of addition (Scheme 115).

These two differences together will push C_1 of the side chain more towards the ring and intensify the steric interactions between H_1 of the side chain and the ring substituent ortho to the tether.

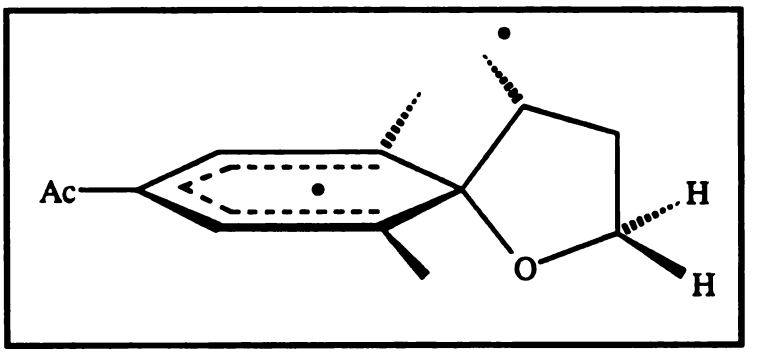


Scheme 115

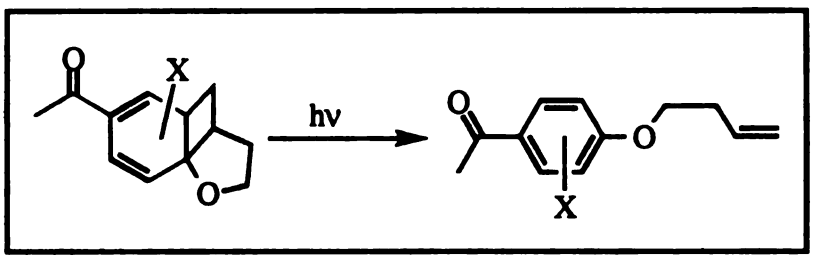
Closure of Biradicals

Once the biradicals are formed, they can either cyclize to the initial photo-adduct or cleave back to the ground state of reactant. It is possible that $k_{ps} \neq k_{pa}$, but in order for the differential biradical partitioning to be totally responsible for the observed regioselectivity $k_{ps} >> k_{pa}$ must hold, since there can be little difference between the rate of the syn and anti biradical decays to the ground state of the starting material. The two biradicals must have essentially the same stability relative to starting material since in both cases the pentadienyl radical moiety is conjugated to X in each mode of addition independent of the geometry of the five-atom ring. Moreover, the syn and anti biradicals do not have similar steric interactions as those observed during exciplex formation and radical addition because the benzene ring carbon baring the tether becomes sp^3 and the

tether oxygen atom as well as C_1 of the tether move away from the plane of the benzene ring leading to almost no interactions with the ring substituents.

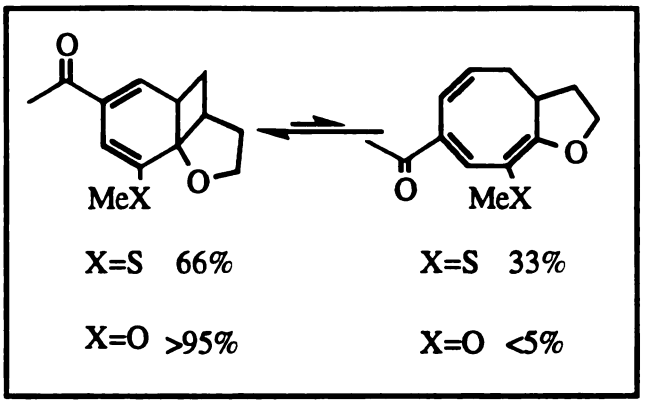


Cyclohexadiene-Cyclooctatriene Equilibrium:



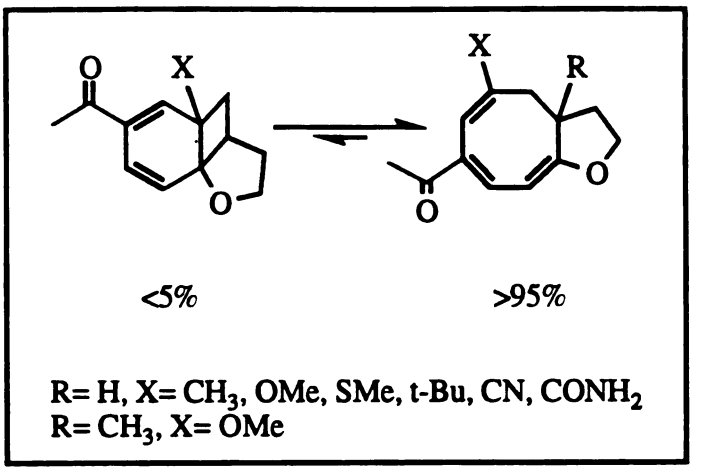
Scheme 116

Another factor that may contribute to regioselectivity is the equilibrium between the primary photoproduct, **CHD**, and its thermal rearrangement product, **COT**. Our results showed that irradiation of **m-OMe-CHD$_a$** led to the formation of the corresponding starting ketone as the major product. Also, irradiation of an equilibrium mixture of **m-SMe-CHD$_a$** and **m-SMe-COT$_a$** led to the formation of the corresponding starting ketone as a minor product.



Scheme 117

It is also known from these and other studies that substituents alter the cyclohexadiene-cyclooctatriene equilibrium.[19,20,28] A methoxy group at C_2 causes the equilibrium to shift towards **m-OMe-CHD$_a$**. The thermal rearrangement product, **m-OMe-COT$_a$**, was not detected by ^{1}H NMR in a sample of **m-OMe-CHD$_a$**, but a small amount could be detected by UV. However, after large scale irradiation of **m-OMe-pBA**, ^{1}H NMR showed the presence of **m-OMe-COT$_a$** as a result of a fast acid catalyzed opening of **m-OMe-ACB$_a$**. After 24 hours, NMR showed the disappearance of peaks corresponding to **m-OMe-COT$_a$** with increasing the intensity of the **OMe-CHD$_a$** peaks. This finding supports the supposition of a slow equilibrium between the two isomers. A thiomethoxy group at C_2 was also found to shift the equilibrium towards **m-SMe-CHD$_a$** as 66% of the product.



Scheme 118

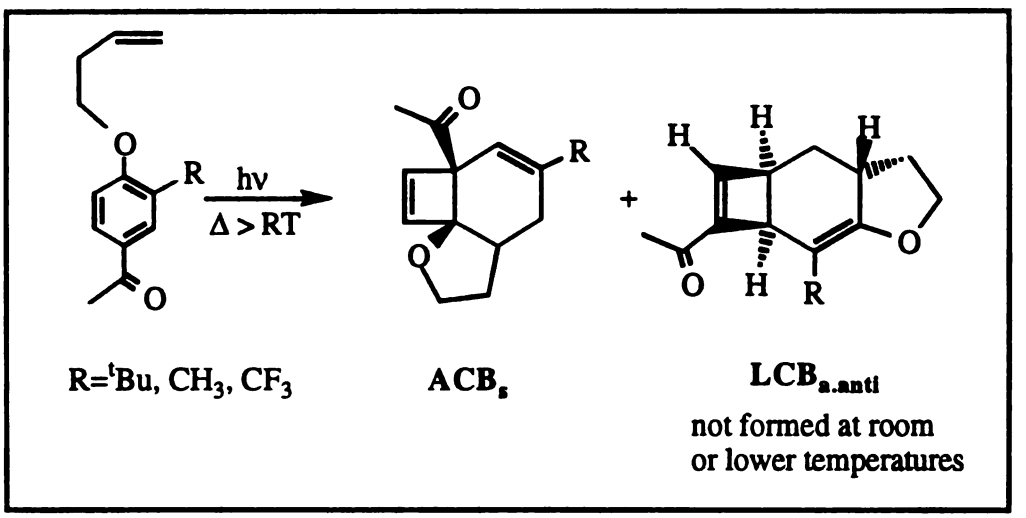
All substituents at C_6 were found to shift the equilibrium towards the cyclooctatriene component. For all the products studied that have a substituent at C_6, no cyclohexadiene was detected by NMR during irradiation of the starting ketone. NMR of the isolated **COT**'s showed no peaks corresponding to any **CHD**. This indicates that in these cases the equilibrium favors the cyclooctatriene which may be due to either the relief of steric interactions that exist in the cyclohexadiene isomer or because of increased conjugation of substituents with the double bonds in the cyclooctatriene.

Could these variations in equilibrium affect the regioselectivity? In the case of **m-OMe-pBA**, it was shown that the equilibrium favors **m-OMe-CHD$_a$**, which was detected at the early stages of the reaction, Also the fact that cyclohexadienes revert photochemically to starting ketone with high efficiency gives an indication that this process will lower the efficiency of the anti cyclization. However, for the other regioisomer, the equilibrium favors the cyclooctatriene. **m-OMe-CHD$_s$** was not detected at any point during irradiation which indicates that it has very low concentration in the reaction medium, thus has a little chance to revert photochemically to the starting ketone. If this process

were responsible for controlling the regioselectivity, it would be expected that the syn isomer to be the major product. However experimental results showed a 6 : 1 ratio of anti to syn cycloaddition products at all reaction stages.

Temperature Effect on Cycloaddition Regioselectivity

Temperature was found to have great effect on the regioselectivity of the cycloaddition. Upon irradiation at room temperature, **m-Me-pBA** gave **m-Me-ACB$_s$** as the only product, favoring the addition syn to the ring substituent. However when the irradiation was performed above room temperature, regioselectivity was reversed and **m-Me-ACB$_s$** and **m-Me-LCB$_{a,anti}$** were obtained in a ratio of 1 : 2



Scheme 119

Similar results were obtained for **m-^{t}Bu-pBA**, since **m-^{t}Bu-ACB$_s$** was formed at room temperature, whereas at higher temperature a mixture of **m-^{t}Bu-ACB$_s$** and **m-^{t}Bu-LCB$_{a,anti}$** was obtained in a ratio of 1 : 10, favoring the addition anti to the *t*-butyl group.

It should be noted that the observed ratios do not reflect the true change in selectivity. Irradiation of both **m-Me-pBA** and **m-^{t}Bu-pBA** at either 0°C or 55°C was monitored by NMR with an internal standard. Material balance decreased with more irradiation, which means that either one or all the products decompose by irradiation. Heating a sample of **m-^{t}Bu-ACB$_S$** at 95°C for 40 minutes did not change it concentration, as shown by NMR. For **m-^{t}Bu-pBA** at 55°C **m-^{t}Bu-LCB$_{a,anti}$** accounted for 20% of the products at about 38% conversion, whereas **m-^{t}Bu-ACB$_S$** accounted for 2.2%. This leaves about 16% unaccounted for. Similarly, **m-Me-pBA** at 35% conversion gave 7.3% of **m-Me-ACB$_S$** and 14% of **m-Me-LCB$_{a,anti}$** which leaves 14% unaccounted for.

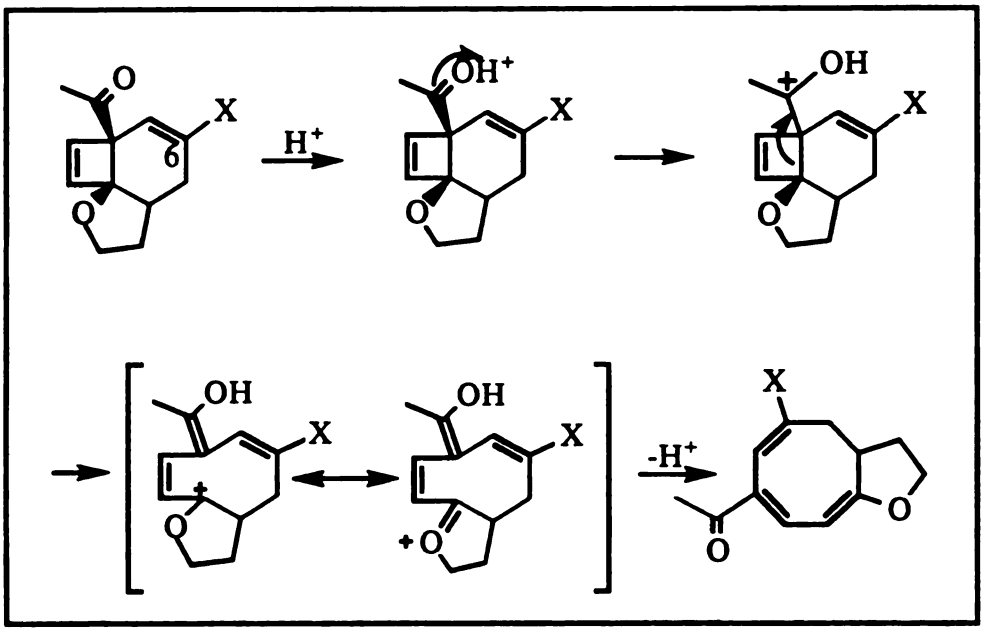
The trifluoromethyl group has a similar effect. At room temperature **m-CF$_3$-ACB$_S$** was obtained favoring the addition syn to the substituent whereas at higher temperature **m-CF$_3$-LCB$_{a,anti}$** was obtained as a minor product besides **m-CF$_3$-ACB$_S$** in a ratio of 1 : 2.

The above results show that increasing the temperature leads to the appearance of the other regioisomer. It may be formed at low temperature in a concentration too low to be detected by NMR. The rate of formation of the anti isomer is more susceptible to temperature change because of its higher activation energy.

Cyclobutene to Cyclooctatriene Rearrangement

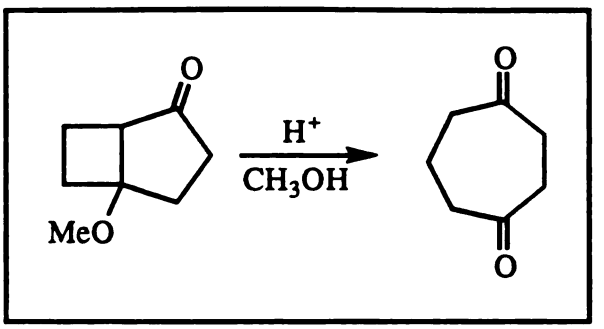
Thermal ring opening of cis-cyclobutene to all cis-cyclooctatriene was proposed to proceed via a stepwise mechanism. A concerted thermal ring opening would produce cis-trans-cis-cyclooctatriene, which was never observed. It is clear from both these and previous studies that rates for thermal opening of cyclobutene to cycloocatatriene vary significantly with structure.[19,20,28] With

carbon anchors the rates are much slower than with oxygen anchors. Moreover, electron-withdrawing substituents at C_6 of the cyclobutenes were found to facilitate the ring opening. Also, the reaction was found to be fast in



Scheme 120

methanol and slow in benzene. Catalytic amount of *p*-toluenesulfonic acid added to the cyclobutene solution in benzene greatly enhanced the reaction and caused the ring to open in seconds. Based on these observations, it is suggested that the reaction is acid catalyzed. A proton from the medium will protonate the acetyl group forming a carbocation, followed by heterolytic cleavage of the C_1—C_4 bond . In the transition state, the developing negative charge on C_4 will be stabilized by the carbocation as well as by any electron withdrawing substituent at C_6. The developing carbocation at C_1 will be stabilized by the α-oxygen atom.

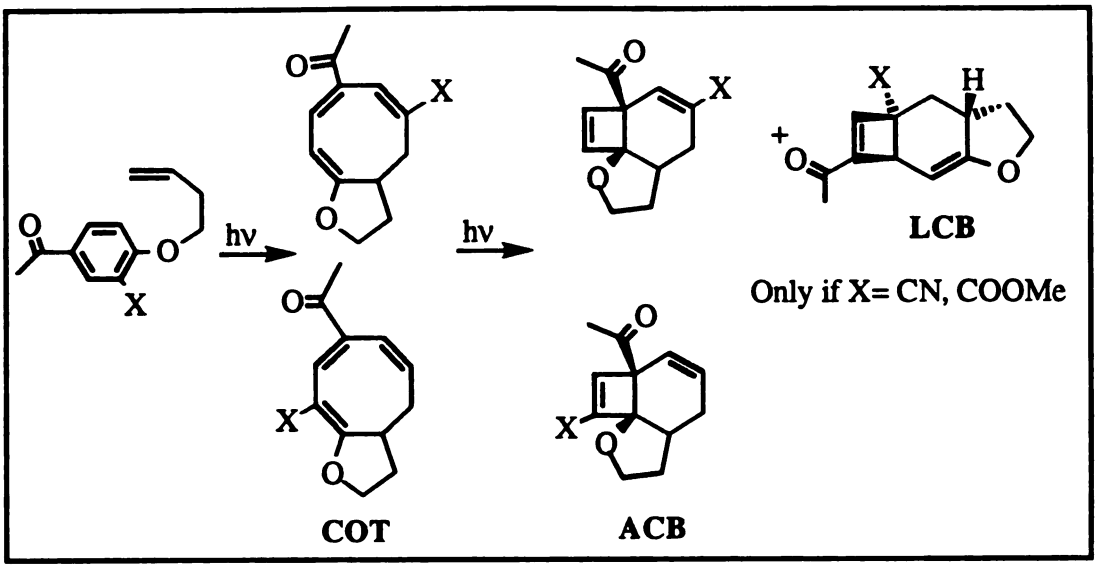


Scheme 121

Chapman and Pasto[103] reported a similar isomerization. They found that 5-methoxybicyclo[3.2.0]heptane-2-one opens rapidly in acid solution to give cycloheptane-1,4-dione (Scheme 121).

Regio- and Stereoselectivity of COT Cyclization

Results from this and previous studies showed that substituted 4-(3-buten-1-oxy)acetophenones cyclize photochemically and yield the corresponding angular cyclobutenes, **ACB**, as the final products[17,18,19,20,28]. **m-Est-pBA** and **m-CN-pBA** are exceptions, since they give a mixture of the corresponding angular (**ACB**) and linear (**LCB**) cyclobutenes.



Scheme 122

AM1 calculations on the excited singlet state of various 6-substituted-4-acetyl-11-oxabicyclo[6.3.0]undeca-1,3,5-trienes were carried out. Results showed that for X= CH_3, *t*-Bu and $CONH_2$, C_1 and C_3 are positively charged whereas C_2, C_4, C_5 and C_6 are negatively charged with C_4 carrying most of the charge. This suggests that cyclooctatriene ring closure to cyclobutene is likely to occur between C_1 and C_4. On the other hand, when X= CN and COOMe, charge distribution showed that ring closure is likely to occur between C_1 and C_4 to give **ACB** and between C_3 and C_6 to give **LCB**. Although the calculations agrees with experimental results, there may be other factors such as steric effects that also contribute to the observed selectivity

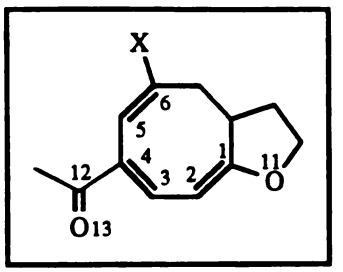
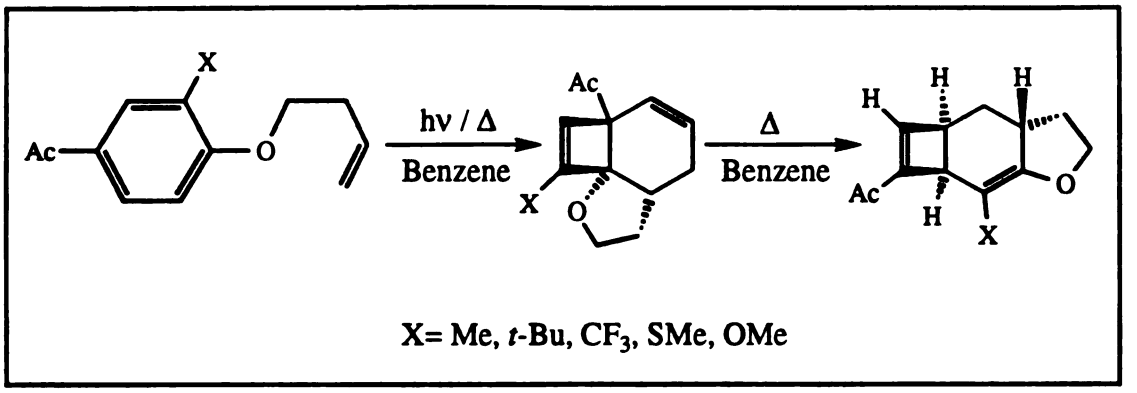


Table 30 : Charge Distribution for the Excited Singlet State of Some COT's

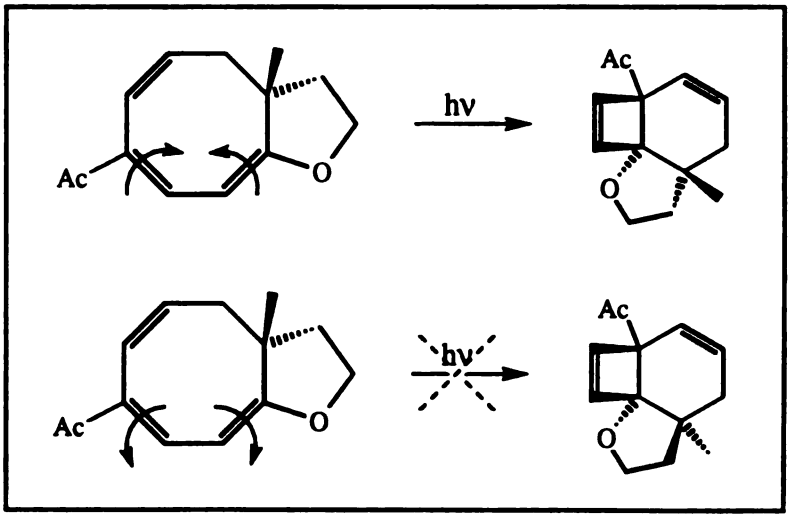
	X=CH_3	X=*t*-Bu	X=$CONH_2$	X=COOMe	X=CN	X=OMe	X=SMe
C_1	+0.35	+0.36	+0.33	+0.34	+0.34	+0.29	+0.33
C_2	-0.14	-0.14	-0.1	-0.13	-0.13	+0.05	-0.23
C_3	+0.29	+0.29	+0.01	+0.3	+0.3	+0.3	+0.34
C_4	-0.67	-0.67	-0.42	-0.54	-0.54	-0.68	-0.68
C_5	-0.11	-0.12	-0.06	-0.06	-0.07	-0.11	--0.11
C_6	-0.17	-0.16	-0.27	-0.35	-0.27	-0.22	-0.22
C_{12}	+0.2	+0.2	+0.2	+0.22	+0.22	+0.2	+0.2
O_{11}	-0.12	-0.12	-0.08	-0.11	-0.1	-0.14	-0.14
O_{13}	-0.44	-0.44	-0.4	-0.37	-0.37	-0.43	-0.43

Irradiation of **m-Me-pBA**, **m-^{t}Bu-pBA**, and **m-CF_3-pBA** in warm benzene led to the formation of the corresponding linear cyclobutene. The reaction presumably involves the formation of the angular cyclobutene as the final photoproduct, which rearranges thermally to the linear cyclobutene. Similar rearrangement was observed in the case of **m-SMe-ACB$_a$** and **m-OMe-ACB$_a$**. They were found to rearrange thermally to **m-SMe-LCB$_{a,anti}$** and **m-OMe-LCB$_{a,anti}$**.



Scheme 123

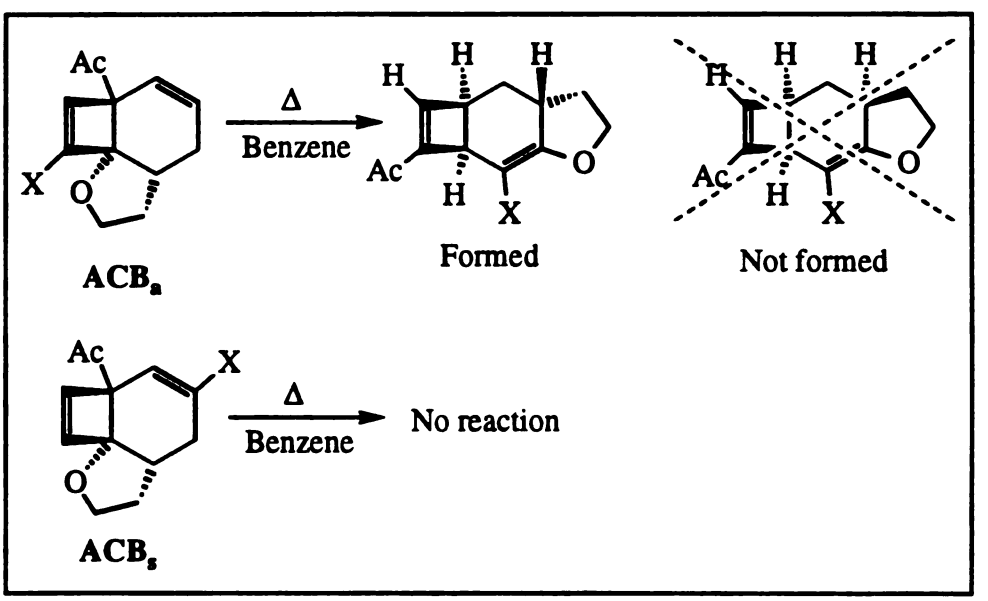
Results from this and previous studies showed that substituted cyclooctatrienes cyclize photochemically stereoselectivelly to the angular cyclobutene with the bridgehead substituent syn to the cyclobutene ring. The disrotatory ring closure occurs only in one direction. The reason for this stereospecificity is not well understood at this moment.



Scheme 124

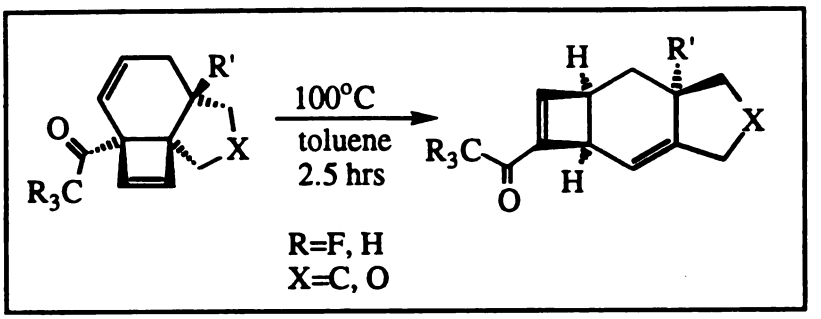
Thermal Chemistry of ACB's

Derivatives of 4-acetyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene, **ACB**, were found to be unstable in acidic media and rearrange to their corresponding cyclooctatrienes. In the absence of acids, the syn addition products **ACB$_s$** were found to be relatively stable. However, warming the anti addition product derivatives **ACB$_a$** led to the formation of 4-acetyl-11-oxatricyclo[6.3.0.0^{3,6}]-undeca-1,4-diene derivatives, **LCB$_{a,anti}$** (Scheme 125).



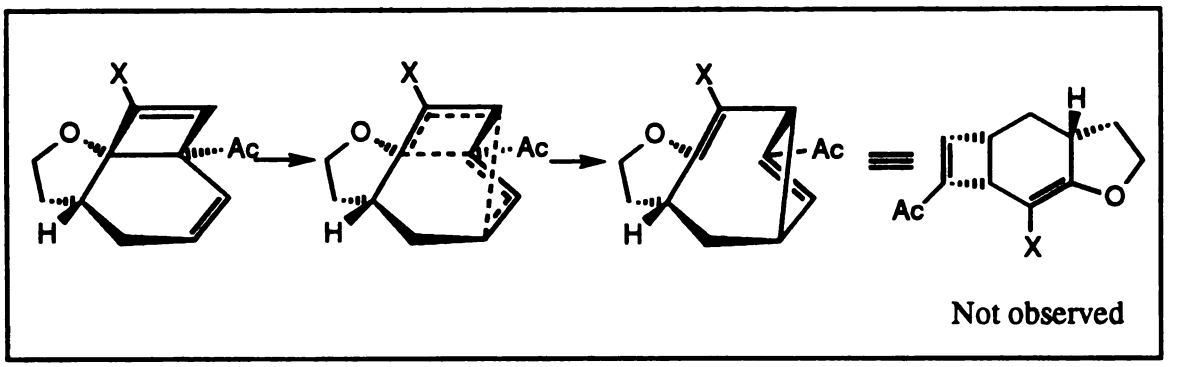
Scheme 125

Alehashem[87] found that similar systems rearrange after heating in toluene and give the corresponding linear cyclobutene derivatives but with the cyclobutene ring syn to the five membered ring. They suggested that the reaction occurred via an antara-antara Cope rearrangement, a process which is thermally allowed and explains the product stereochemistry (Scheme 126).



Scheme 126

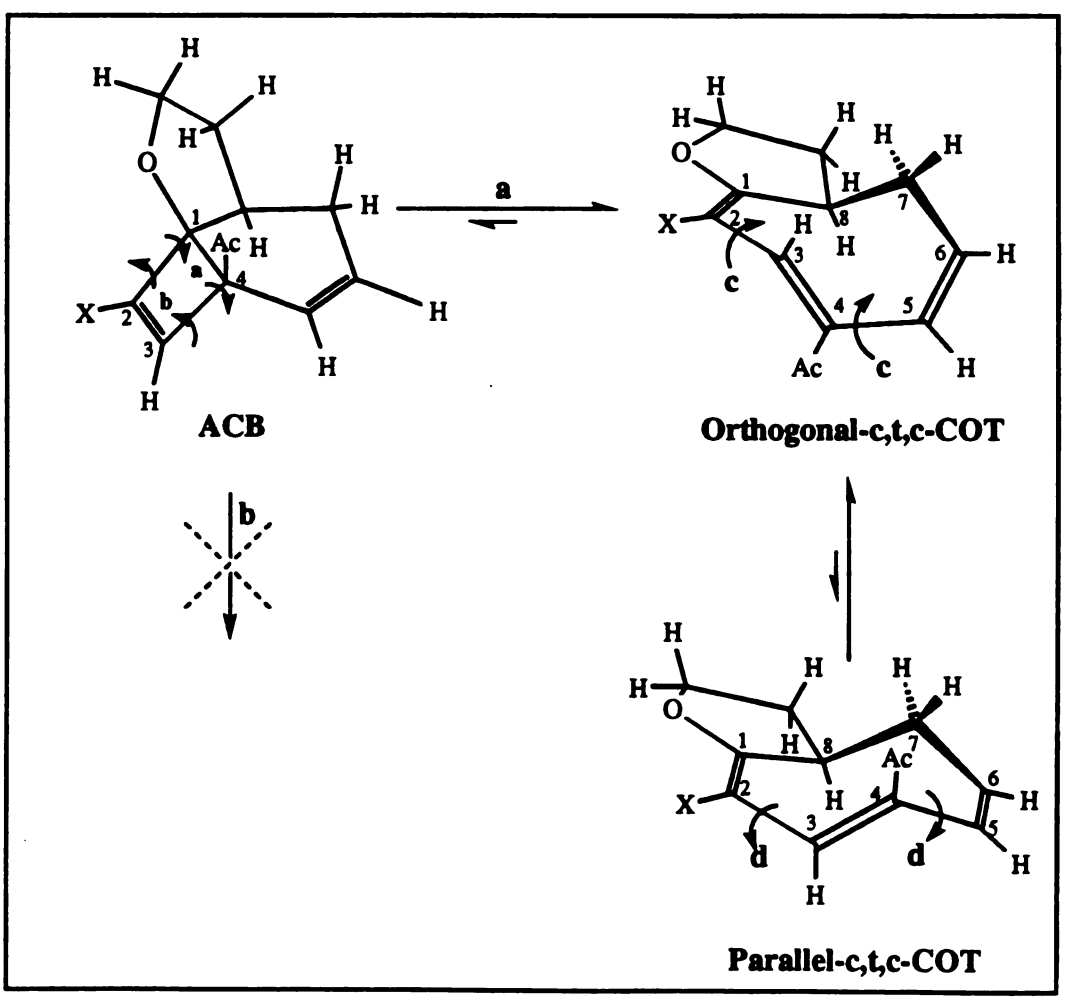
Applying the Cope rearrangement mechanism to the thermal transformations observed in this work leads to products having the cyclobutene ring syn to the five-membered ring. The actual stereochemistry of the products is anti, i.e. the cyclobutene ring is anti to the five-membered ring (Scheme 127). This indicates that the rearrangement occurs by a different mechanism.



Scheme 127

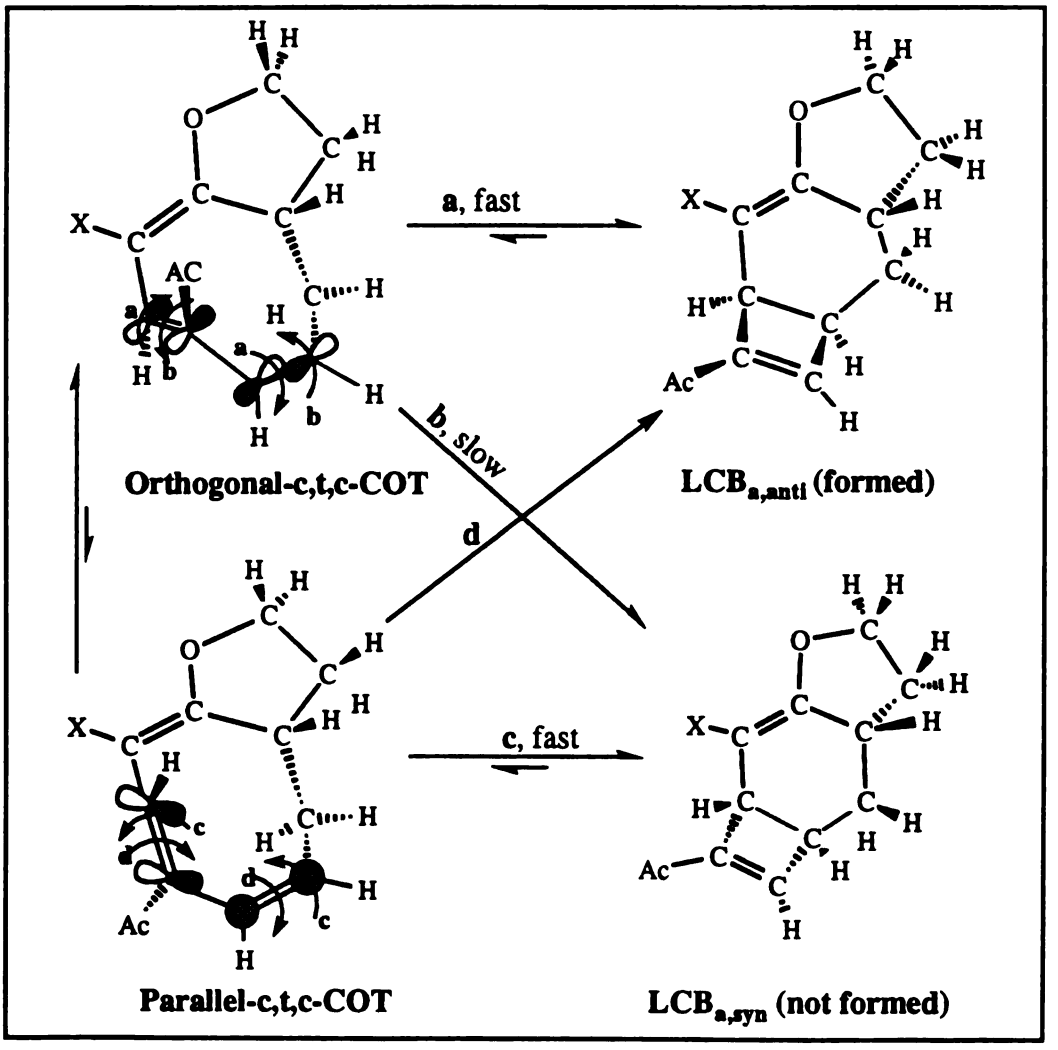
An alternative mechanism involves the formation of the corresponding cis-trans-cis-cyclooctatriene which then closes to the final product. This mechanism is similar to the one used by Baldwin for a similar transformation.[81] In our system, the angular cyclobutene **ACB** can open thermally in a symmetry allowed conrotatory process (route **a**) to give cis,trans,cis-cyclooctatriene at which the C_3—C_4 bond is orthogonal to the C_7—C_8 bond (**Orthogonal-c,t,c-COT**). Route

b is impossible because of the very high strain of the resulting product. By rotation around C_2—C_3 and C_4—C_5 bonds (route **c**), **Orthogonal-c,t,c-COT** can interconvert to another cyclooctatriene in which the C3—C4 bond is parallel to the C_7—C_8 bond (**Parallel-c,t,c-COT**) (Scheme 128). AM1 calculations showed that **Orthogonal-c,t,c-COT** is about 2-3 kcal/mol more stable than **Parallel-c,t,c-COT**, which means that **Parallel-c,t,c-COT** contributes less than 4% to an equilibrium mixture of the two isomers. On the other hand, the activation energy of this transformation is very high because it requires the molecule to be flat with H_3 pointing inside the ring. This will dramatically increase strain energy and steric interactions during the transformation.



Scheme 128

The initially formed **Orthogonal-c,t,c-COT** can either close to the linear cyclobutene, **$LCB_{a,anti}$** (route **a**), close to the linear cyclobutene, **$LCB_{a,syn}$** (route **b**), revert to **ACB**, or interconvert to **parallel-c,t,c-COT** (Scheme 129). AM1 calculations showed that **Orthogonal-c,t,c-COT** and **$LCB_{a,anti}$** have very similar geometries and only a slight conrotatory rotation around C_3—C_4 and C_5—C_6 bonds of **COT** (route **a**) is required to form **$LCB_{a,anti}$** through a symmetry allowed process. This implies that this step is fast with a relatively small activation energy.

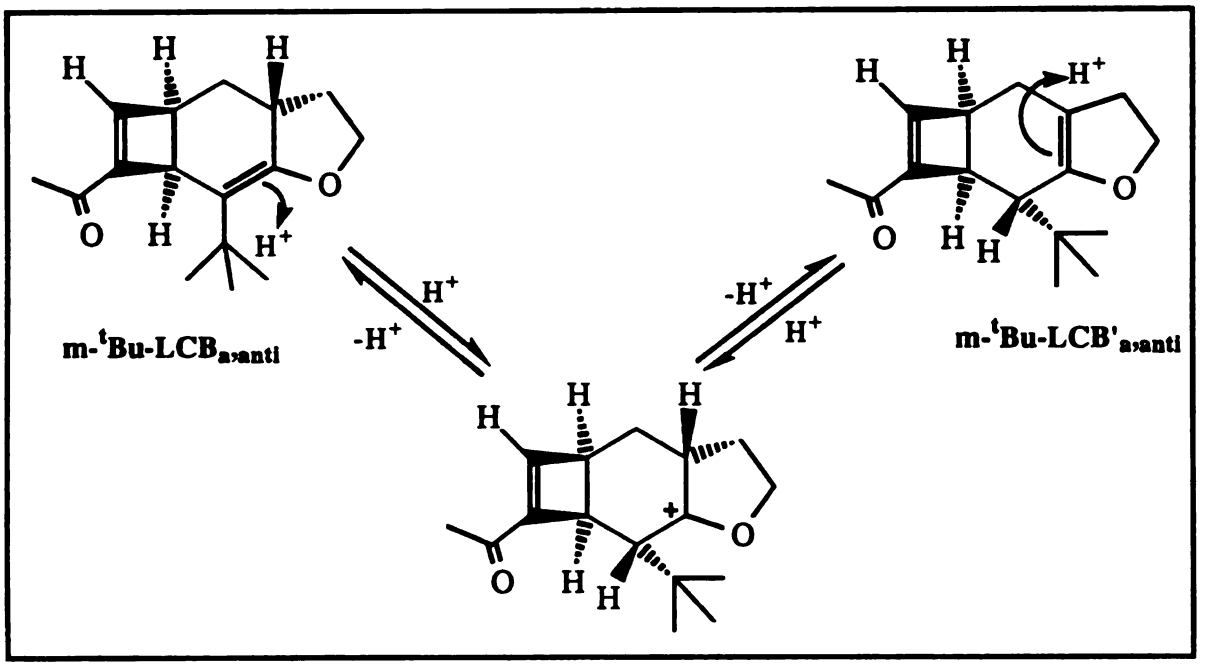


Scheme 129

On the other hand, AM1 calculations showed that **Orthogonal-c,t,c-COT** and **$LCB_{a,syn}$** have different geometries and a > 270° conrotatory rotation around C3—C4 and C5—C6 bonds of **COT** (route **b**) is required to form **$LCB_{a,syn}$**. The least motion principle[2] suggests that route **a** predominates over route **b**. Moreover, route **a** is suggested to be much faster than interconversion to **parallel-c,t,c-COT**. This means that **Orthogonal-c,t,c-COT** can either form **$LCB_{a,anti}$** or revert to **ACB**. AM1 calculations showed that **LCB**'s are 4-7 kcal/mol more stable than their corresponding **ACB**'s, which means that **$LCB_{a,anti}$** will predominate over the formation of other products if the whole system is in equilibrium.

Rearrangement of m-^{t}Bu-LCB$_{a,anti}$

Attempts to isomerize **^{t}Bu-LCB$_{a,anti}$** to the corresponding cyclooctatriene using catalytic amount of para toluenesulfonic acid led to the formation of an equilibrium mixture of **^{t}Bu-LCB$_{a,anti}$** and **^{t}Bu-LCB'$_{a,anti}$**.

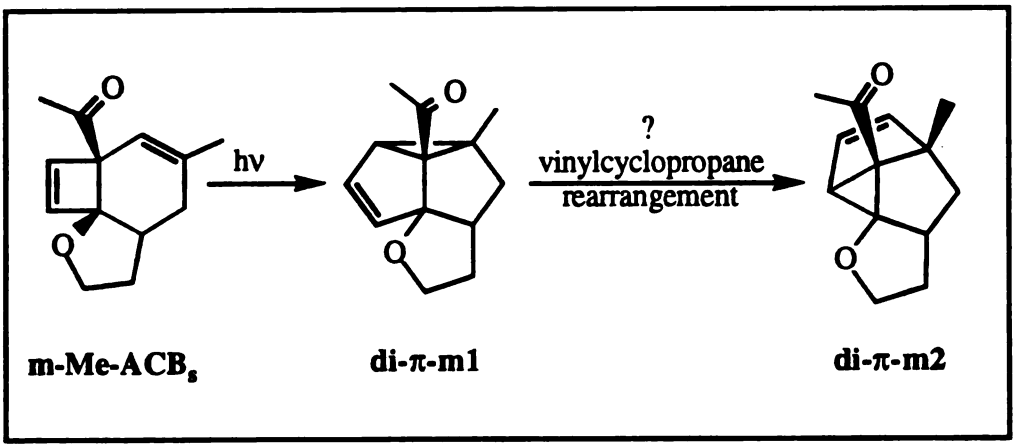


Scheme 130

The isomerization proceeded via protonation of C_2 to form an α-alkoxy tertiary carbocation at C_1. Deprotonation of H_8 led to the formation of **^{t}Bu-LCB'$_{a,anti}$** whereas deprotonation of H_2 led to reversion to starting material. Similarly, treatment of **^{t}Bu-LCB'$_{a,anti}$** with acid led to the formation of the same equilibrium mixture of the two cyclobutenes. Once more, the same carbocation is formed giving the same product ratio. The stereospecifity observed in both rearrangements may be attributed to facial selectivity during the protonation step.

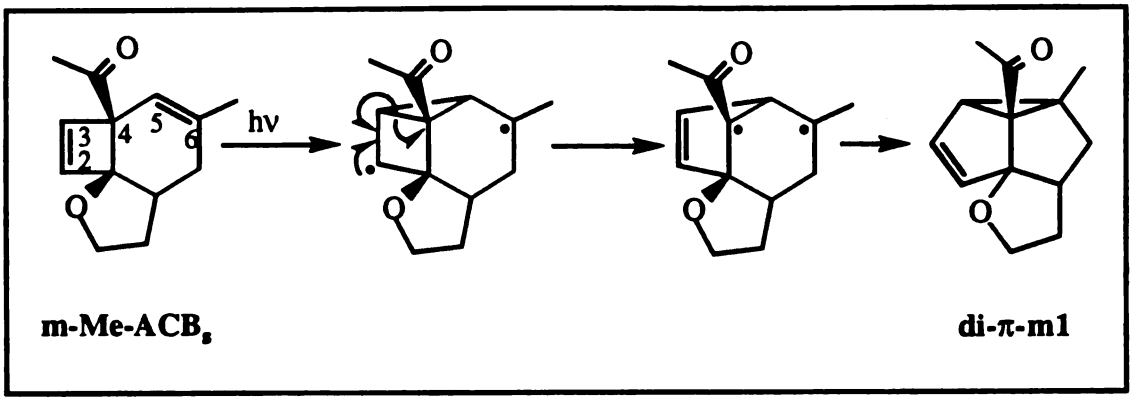
The Di-π–Methane Rearrangement

Irradiation of **m-Me-pBA** at $\lambda \geq 290$ led to the formation of **m-Me-ACB$_S$** at the early stages of the reaction. Prolonged irradiation led to the formation of a new product which is proposed to be either **di-π–m1** or **di-π–m2**. When irradiation was performed at $\lambda \geq 334$, where **m-Me-ACB$_S$** is not expected to absorb, no di-π–methane product was observed.



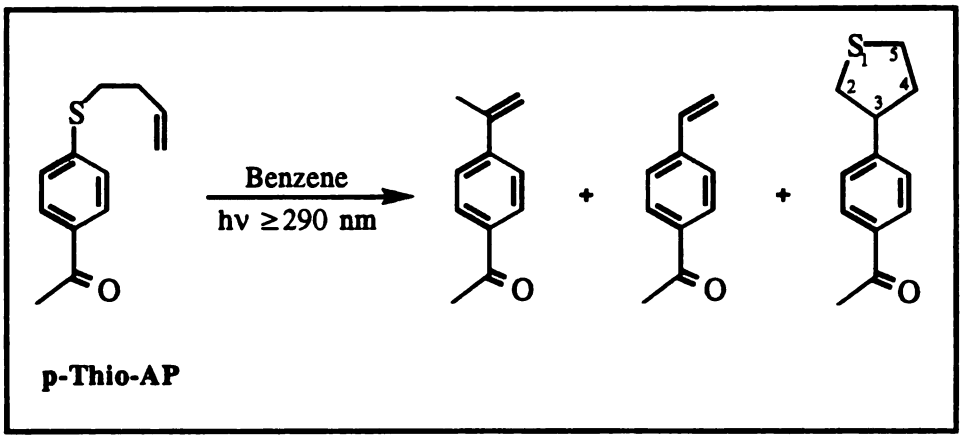
Scheme 131

The mechanism of the reaction involves bonding between C_3 and C_5 of **m-Me-ACB$_S$** to form a cyclopropane ring and two radical centers at C_2 and C_6. Homolytic cleavage of the C_3—C_4 bond lead to the formation of a double bond between C_2 and C_3 and a 1,3 biradical at C_4 and C_6 which gives **di-π–m1** upon closure. The specificity in cleaving C_3—C_4 bond instead of C_4—C_5 is driven by the relief of the four membered ring strain. **di-π–m1** can undergo vinyl-cyclopropane rearrangement leading to the formation of **di-π–m2**. The two compounds are indistinguishable by NMR.



Scheme 132

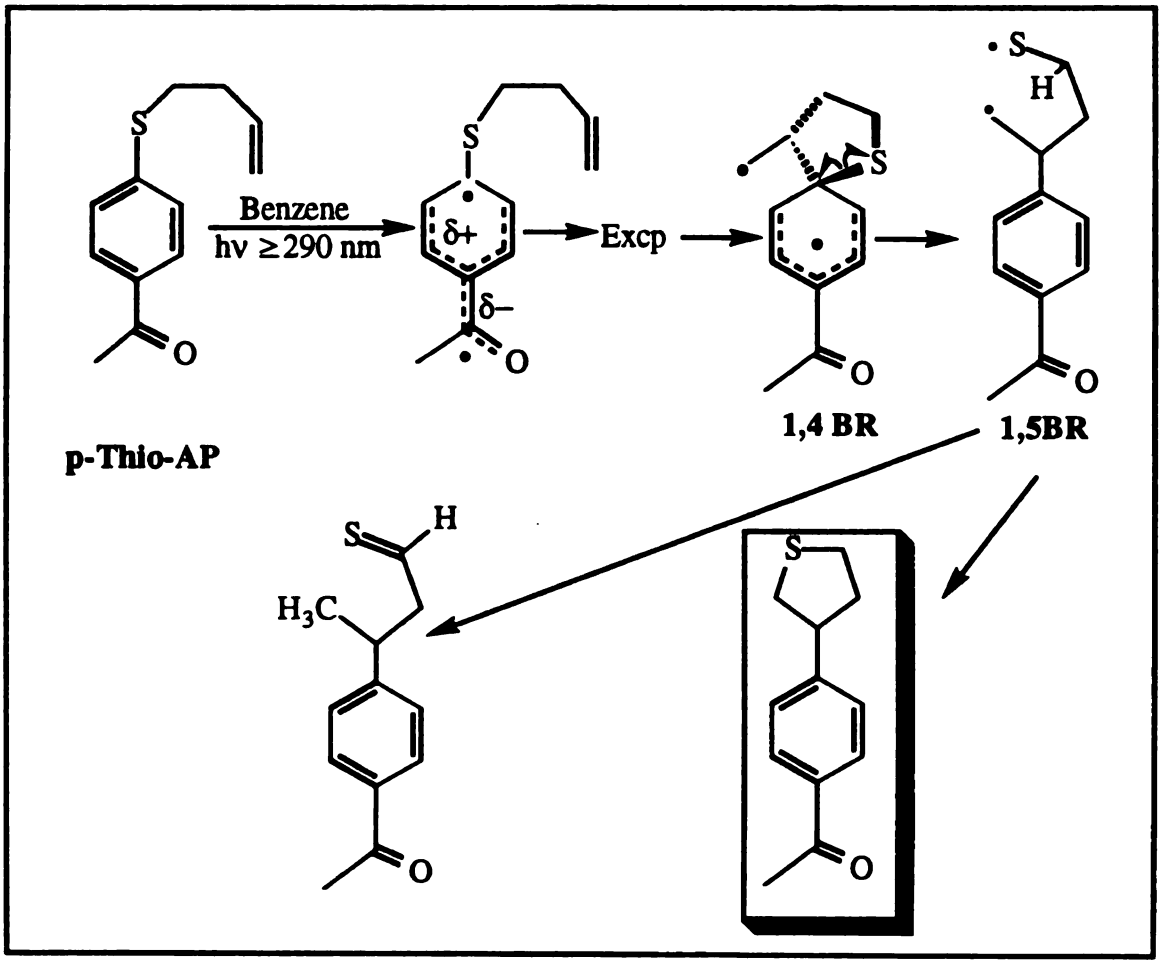
Photochemistry of 4-(3-buten-1-mercapto)acetophenone:



Scheme 133

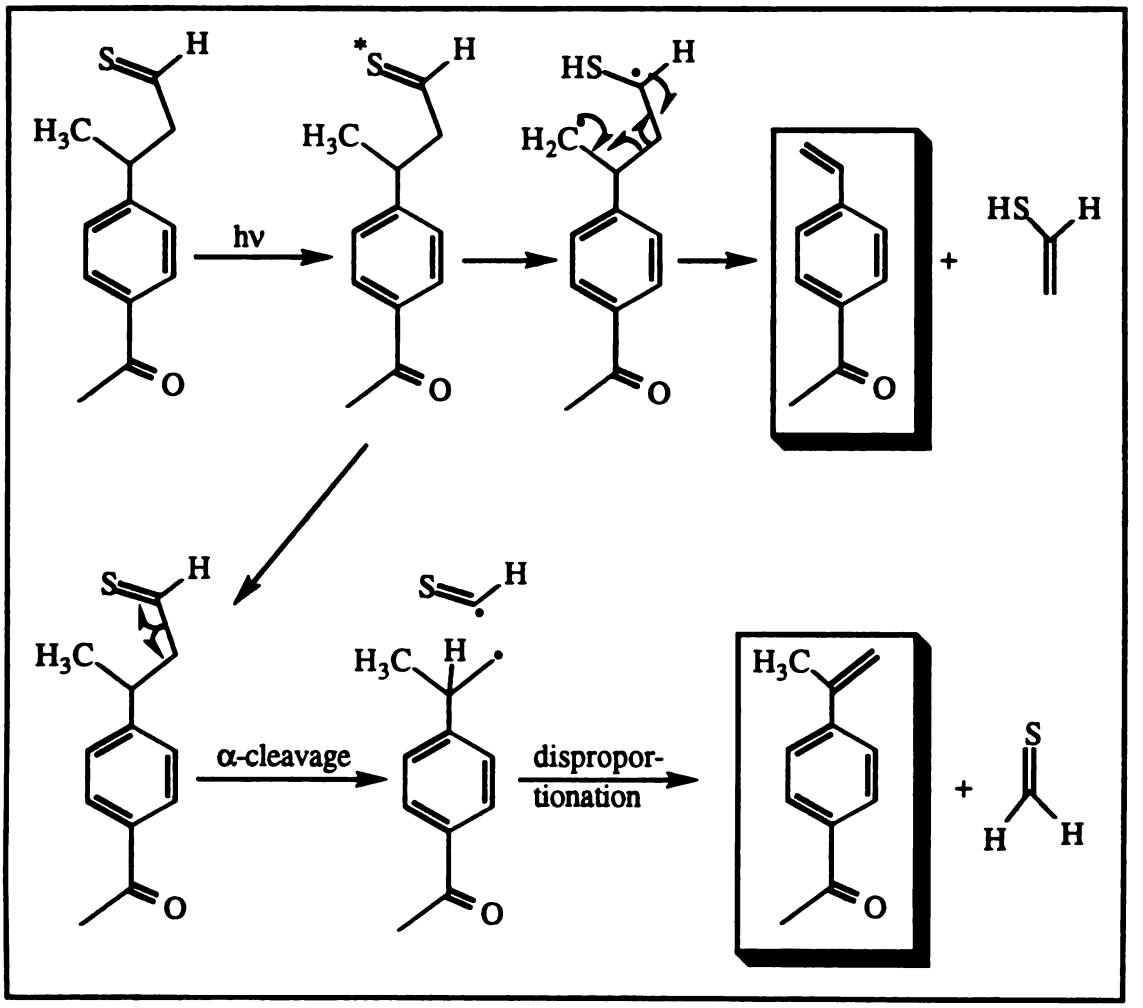
The photochemistry of **p-Thio-AP** was investigated in order to check the possibility of incorporating a sulfur atom in the polycyclic product systems. Previous work showed that 4-thiomethoxyacetophenone has a lowest π,π^* triplet with energy of 64 kcal/mol.[12] So it was assumed that **p-Thio-AP** will react similarly to its oxygen analog. Irradiation of the compound gave no cycloaddition product. Instead, 4-acetylstyrene, 4-acetyl-α-methylstyrene and 3-(4-acetyl-phenyl) tetrahydrothiophene were obtained.

The reaction mechanism is proposed to be similar to that of the oxygen analog up to 1,4 biradical formation. The 1,4 biradical in the case of the oxygen analog either couples to give the primary cycloaddition product or cleaves efficiently to the starting ketone. In case of the biradical driven from **p-thio-Ap**, C—S bond cleavage apparently is much faster than both the radical cyclization and the C—C bond cleavage. The 1,5 sulfur biradical can either cyclize to give 3-(4-acetyl-phenyl) tetrahydrothiophene or disproportionate to give the corresponding thioaldehyde (Scheme 134).



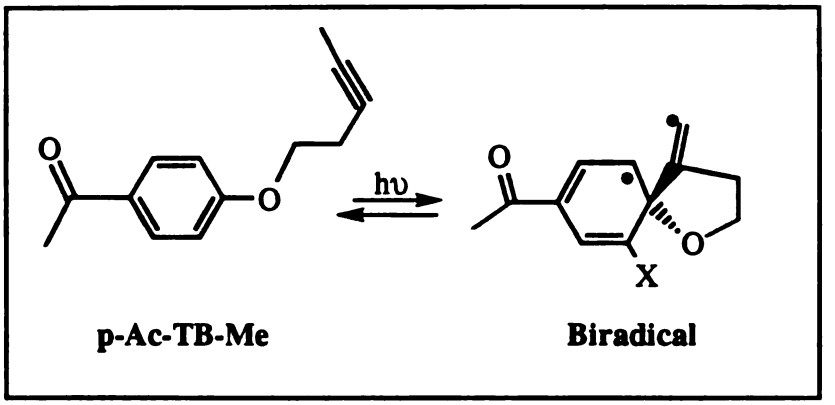
Scheme 134

The thioaldehyde is assumed to be excited either by direct irradiation or by triplet energy transfer from the arylcarbonyl moiety. Following the excitation γ-hydrogen abstraction will occur to give a 1,4 biradical which will undergo β-cleavage and yield 4-acetylstyrene and an olefin. On the other hand, the excited thion may also undergo α-cleavage followed by disproportionation to give 4-acetyl-α-methylstyrene and thiofomaldehyde (Scheme 135)



Scheme 135

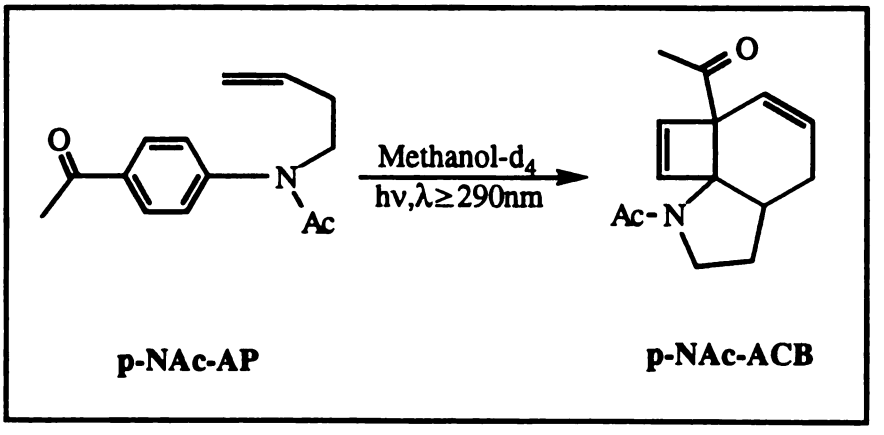
Photochemistry of Triple Bond Derivatives



Scheme 136

Irradiation of **o-Ac-TB-H** gave no cycloaddition products, instead, it led to the formation of other products presumably arising from hydrogen abstraction reaction. On the other hand, **p-Ac-TB-Me** was photostable even after irradiation for 48 hours at $\lambda \geq 290$ nm. The lack of reactivity is presumably due to a fast efficient cleavage of the formed vinylic 1,4 biradical which may be due to the high strain during the closure of the biradical.

Photochemistry of The Amino Derivatives

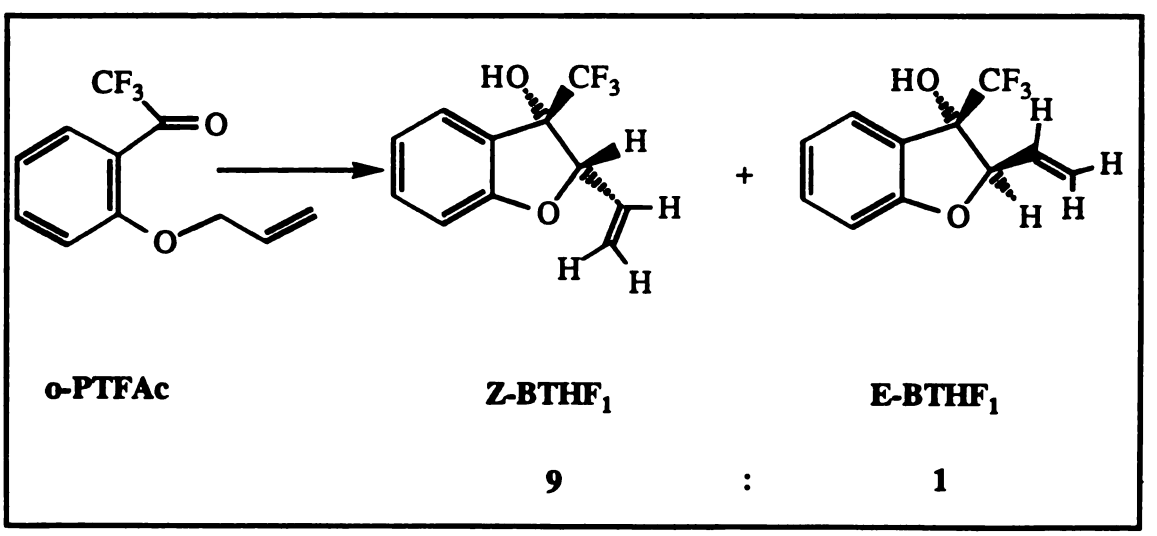


Scheme 137

p-NH-AP was found to be photostable. It gave no products after irradiation for 48 hours. However, its *N*-acetyl derivative, **p-NAc-AP**, underwent photocycloaddition and gave **p-NAc-ACB** as a product. The lack of reactivity of **p-NH-AP** presumably is due to charge transfer quenching of the triplet state by the nitrogen. Introducing an *N*-acetyl group led to the involvement of the nitrogen lone pair in bonding with the acetyl group, hence, it became unavailable for quenching the reaction.

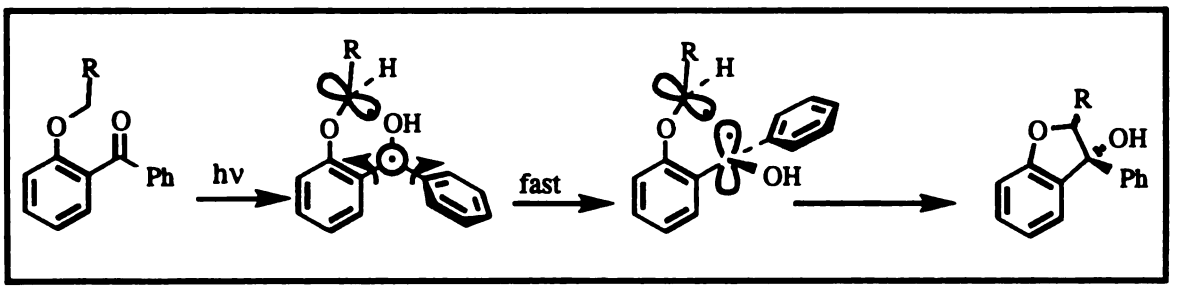
Photochemistry of o-Allyloxy Trifluoroacetophenone

The photochemistry of *o*-allyloxy trifluoroacetophenone was studied in order to see whether enhanced reactivity of the triplet might allow cycloaddition with a shorter tether. Instead, no cycloaddition was observed and δ-hydrogen abstraction occurred to provide *Z*- and *E*-3-hydroxy-3-trifluoromethyl-2-vinyl-2,3-dihydro-benzofuran (**Z-BTHF$_1$** and **E-BTHF$_1$**) with a ratio of 9 : 1



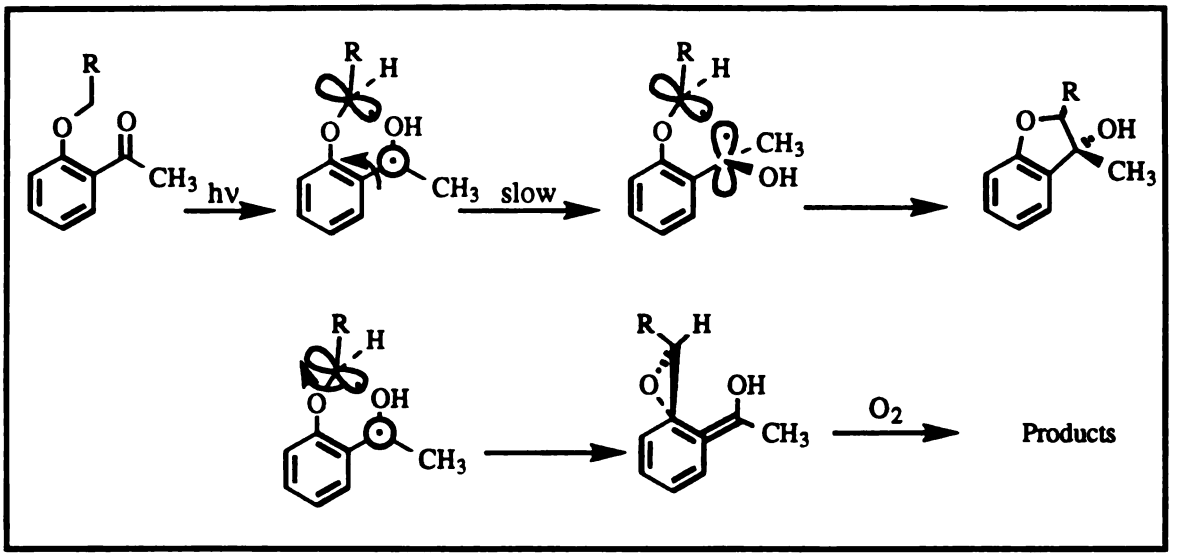
Scheme 138

This finding is very interesting since it shows that 1,5 biradicals derived from *o*-alkoxy trifluoroacetophenones behave like their benzophenone analogs. On the other hand, biradicals derived from similar acetophenones behave differently.[104]



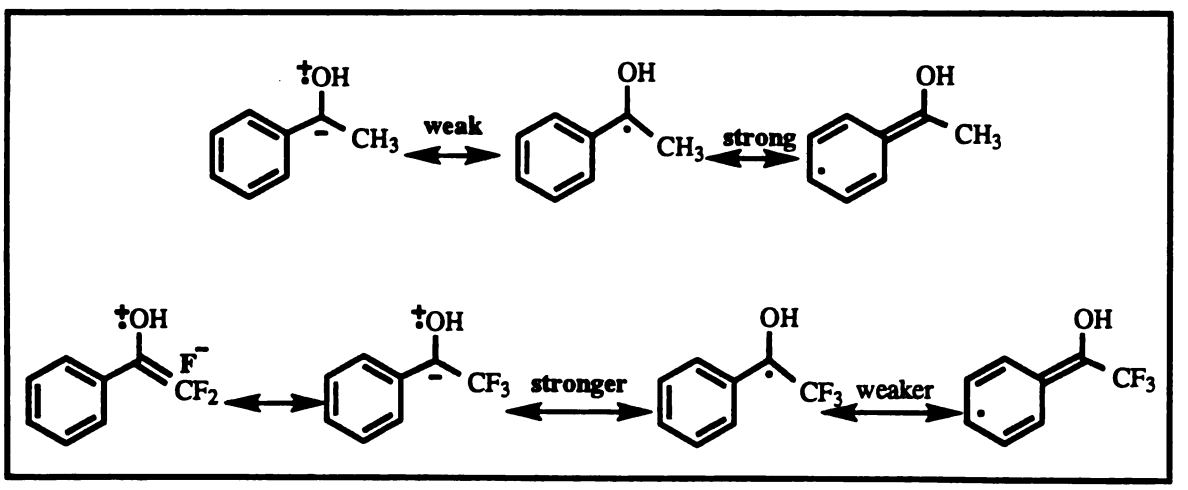
Scheme 139

Wagner explained the difference of behavior in terms of the rotational barrier around the aryl group and benzylic radical center.[104] This rotation is the key step to reach the required conformation for five-membered ring formation (Scheme 139). In case of acetophenones, this rotation will twist the benzylic radical center out of conjugation. This restricted rotation allows the formation of the spirocyclic compound which is the key step for other product formation. In the benzophenone-derived biradicals, rotation required for the five-membered ring formation is faster because the second phenyl ring can twist and thus maintain full benzylic conjugation (Scheme 140)



Scheme 140

In case of the trifluoroacetyl derivative, the similar behavior to the benzophenone derivative suggests that rotation around the benzyl bond is facile in the intermediate biradical. This can be explained by the hypothesis that fluorine hyperconjugation may enhance the charge separated resonance form of the hydroxy radical center and minimize the benzylic conjugation that impedes benzylic bond rotation (Scheme 141).



Scheme 141

EXPERIMENTAL

General Procedures

All ^{1}H NMR and ^{13}C NMR spectra were obtained using a 300 MHz Varian Gemini, a 300 MHz Varian VXR-300 or a 500 MHz Varian VXR-500 instrument. All the IR spectra were recorded on a Nicolet 2R/42 Fourier Transform IR spectrometer. UV spectra were recorded on a Shimadzu UV-160 spectrometer. Mass spectra were recorded on a Finigan 4000 GC/MS, Hewlett Packard 5890 GC/MS trio-1 and a Joel JMS-HX100 Mass spectrometer. Gas chromatographic analysis were performed on Varian 1400 or 3400 machines with flame ionization detector. Data were recorded on either a Hewlett-Packard HP3392A, HP3393A or HP 3395A integrators. Three types of columns were used for GC; Megabore DB1, Megabore DB210 and Megabore DB225. For column chromatography, Mallinckrodt silica gel 60 (230 - 300 mesh) was used. For preparative TLC, Analtech Uniplate silica gel plates of 20 X 20 cm, 1000 micron were used. Melting points were recorded using Thomas Hoover Capillary Melting Point Apparatus.

Purification of Chemicals

Benzene:[105] 3.5 L of reagent grade benzene was stirred with 0.5 L of concentrated sulfuric acid for 24 hours. The benzene layer was separated and extracted with 200 ml portions of concentrated sulfuric acid several times until the sulfuric acid layer does not turn yellow. After separating the benzene, it was washed with distilled water then with saturated sodium carbonate solution and dried over anhydrous magnesium sulfate. It was then filtered into a 5 L round

bottomed flask, about 100 gm of phosphorous pentoxide was added and refluxed overnight. Then benzene was distilled through a meter column packed with stainless steel helices. The first and final 10% portions were discarded. (b.p.:78°C)

Methanol:[106] 100 ml of reagent grade absolute methanol, 5.0 gm of magnesium turnings and 0.5 gm of iodine were placed in 2 L round bottomed flask and refluxed until all magnesium reacted. Then 900 ml of methanol was added and the mixture was refluxed for 30 minutes and distilled through a half meter fractionating column (b.p.: 65°C). The first and last 10% portions were discarded.

Irradiation Procedures

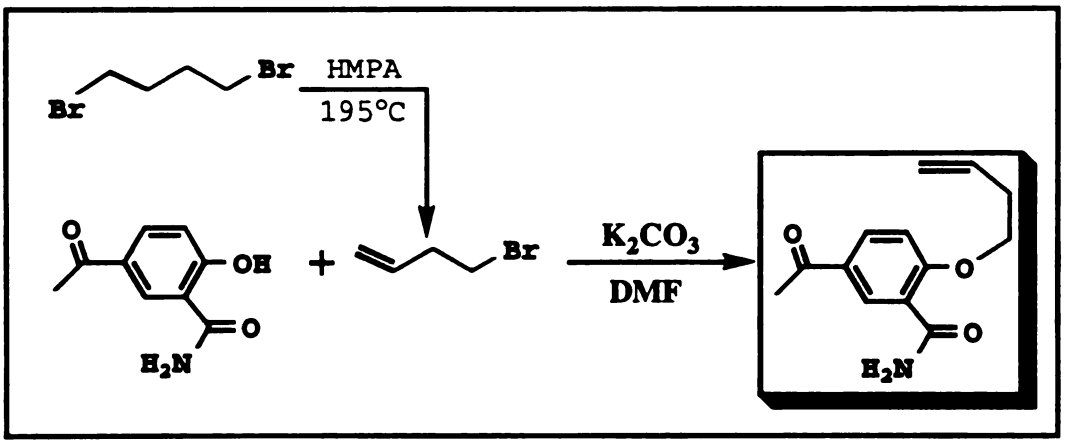
0.01-0.03 M solution of ketones in deuterated methanol or benzene was placed in an NMR tube. The tube was stoppered with a rubber septum, then the solution was purged with argon using a long needle. Then the top of the tube was wrapped with Teflon tape to prevent the diffusion of air. Irradiations were performed with medium pressure mercury arc filtered through pyrex so as to cut any wave length below 290 nm. In some cases wave lengths of 313, 365 or > 334 nm were used for irradiation. ^{1}H NMR spectroscopy was used to follow the reaction course. Generally 4-acetyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**Linear Cyclo Butene, LCB**) and/or 4-acetyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**Angular Cyclo Butene, ACB**) derivatives were the final photoproducts if the NMR were taken immediately after irradiation.

Large scale irradiations were performed using ~0.3 gm of ketone in argon bubbled methanol or benzene. Solutions were placed in container surrounding the immersion well. Hanovia 450 W medium pressure lamp with a Pyrex filter tube

was used as a light source. Products were usually isolated by column chromatography or preparative TLC using hexanes/ethyl acetate as eluent.

Preparation of Starting Ketones

4-Acetyl-1-(3-buten-1-oxy) benzamide (m-Amide-pBA):



4-Bromo-1-butene:

Caution: Hexamethylphosphoric triamide is highly toxic cancer suspect agent. The experiment was done in the fume hood and all the waste was placed in labeled containers and disposed of by qualified personnel.

The title compound was prepared according to the general procedure of Kraus and Landgrebe for bromo-alkenes.[107] Hexamethylphosphoric triamide (150 ml) was added dropwise to stirred 1,4-dibromo butane (180.0 g, 100 ml, 0.83 mol) at 195°C. The product was distilled off from the reaction mixture as soon as it is formed and was collected into a dry ice-cooled rb flask. After the rate of product formation decreased, reaction temperature was raised to 220°C for 5 minutes. The product was redistilled at atmospheric pressure (found 94-95°C, lit 99-100°C) to give 58.5 g, (52%).

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.6 (tq, *J* = 1.19, 6.9 Hz, 2H), 3.39 (t, *J* = 7.05 Hz, 2H), 5.11 (ddt, *J* = 10.43, 1.64, 1.16 Hz, 1H), 5.12 (dq, *J* = 17.0, 1.59 Hz, 1H), 5.78 (ddt, *J* = 10.31, 16.98, 6.66 Hz, 1H)

m-Amide-pBA:

4-Bromo-1-butene (2.25g, 0.017 mol) was added to a mixture of 5-acetyl salycilamide (Aldrich) (3.0 g, 0.017 mol) and anhydrous potassium carbonate (3.0 g, 0.022 mol) in 30 ml of dry DMF. The mixture was stirred at 50°C for 5 days under argon atmosphere, water was added and the product was extracted with ethyl acetate. The organic layer was washed four times with 10% sodium hydroxide solution and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford 3.4 g of yellowish solid which was crystallized from benzene to give 2.8 g of white crystals (mp: 112-113°C), (72%).

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.59 (s, 3H), 2.65 (tq, *J* = 1.32, 6.3 Hz, 2H), 4.26 (t, *J* = 6.2 Hz, 2H), 5.17 (ddt, *J* = 9.92, 1.34, 1.38 Hz, 1H), 5.22 (dq, *J* = 17.21, 1.55 Hz, 1H), 5.88 (ddt, *J* = 17.1, 10.26, 6.72 Hz, 1H), 6.18 (broad, s, 1H), 7.02 (d, *J* = 8.8 Hz, 1H), 7.71 (broad, s, 1H), 8.10 (dd, *J* = 2.41, 8.73 Hz, 1H), 8.76 (d, *J* = 2.47 Hz, 1H)

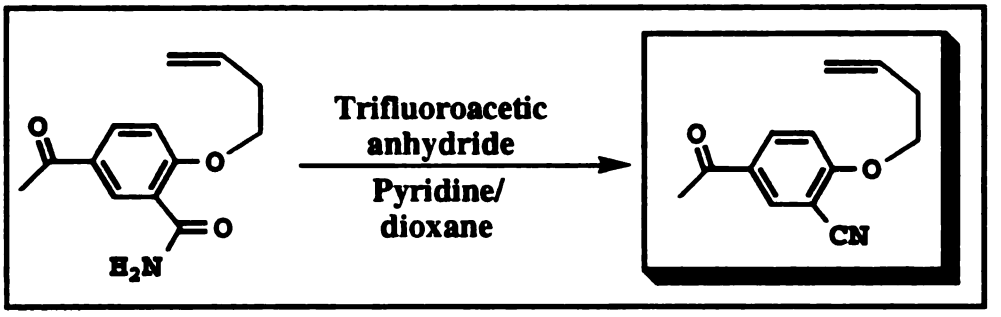
^{13}C NMR ($CDCl_3$) (75 MHz): δ 26.37, 33.39, 68.34, 112.30, 118.18, 120.44, 130.50, 133.11, 133.74, 133.8, 160.45, 166.16, 196.4

IR ($CHCl_3$): 3511, 3391, 3005, 1667, 1580, 1497, 1426, 1364, 1260, 1156 cm^{-1}

MS (m/e): 233 (M^+), 203, 188, 179, 162, 147, 129, 119, 107, 91, 79, 63, 55 (base), 43

Hi-Res MS: $C_{13}H_{15}NO_3$, Calculated: 233.1052, Found 233.1056

4-(3-Buten-1-oxy)-3-cyanoacetophenone (m-CN-pBA):



The amide group of **m-Amide-pBA** was dehydrated according to the procedure of Campagna and coworkers[108], trifluroaceticanhydride (2ml, 0.014 mol) in 5 ml anhydrous dioxane was added to ice cooled suspension of 4-acetyl-1-(3-buten-1-oxy) benzamide in anhydrous dioxane (15 ml) and anhydrous pyridine (2.1 ml, 0.026 mol). The solution temperature was kept below 5°C during the addition, then it was kept at room temperature overnight, water was added and the product was extracted with ether. The organic layer was washed with 10% HCl (2 X), water (1 X) then with 10% sodium hydroxide solution (1 X) and dried over anhydrous magnesium sulfate. Solvent was removed using rotary evaporator and the product was purified using silica gel column (20% ethyl acetate/hexanes), then crystallized from benzene/hexane to provide 2.0 g of white crystals (mp: 53-54°C), (72%).

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.54 (s, 3H), 2.62 (ddq, *J* = 1.31, 1.26, 6.73 Hz, 2H), 4.17 (t, *J* = 6.75 Hz, 2H), 5.13 (ddt, *J* = 10.23, 1.65, 1.16 Hz, 1H), 5.19 (dq, *J* = 17.18, 1.56 Hz, 1H), 5.88 (ddt, *J* = 17.13, 10.27, 6.8 Hz, 1H), 7.00 (d, *J* = 8.76 Hz, 1H), 8.11 (dd, *J* = 8.61, 2.26 Hz, 1H), 8.14 (dd, *J* = 2.23, 0.58 Hz, 1H)

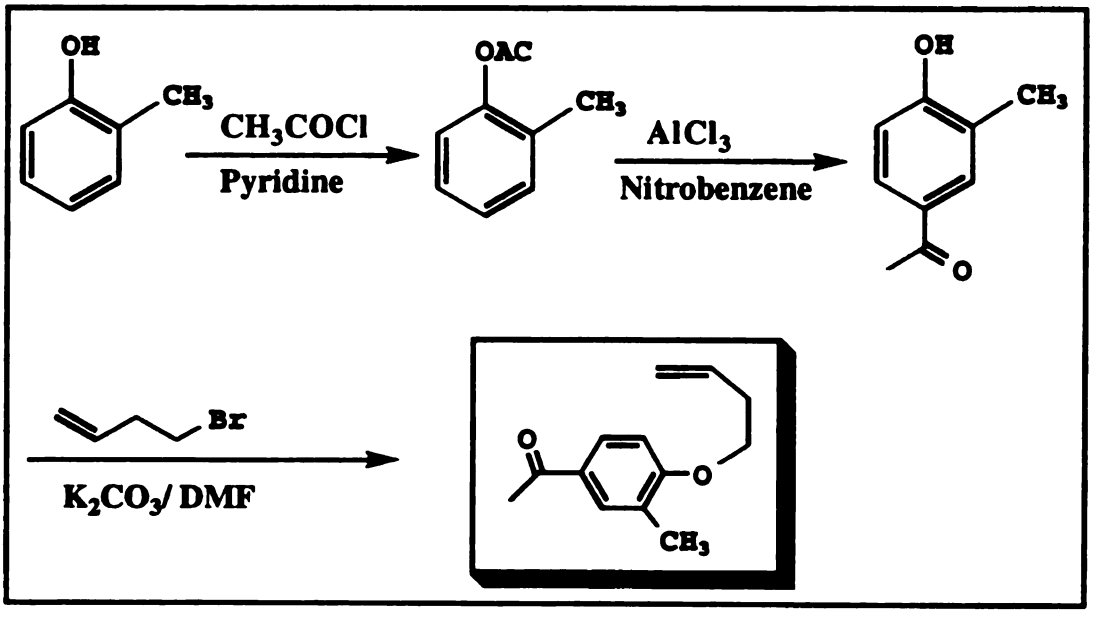
^{13}C NMR ($CDCl_3$) (75 MHz): δ 26.25, 33.07, 68.81, 102.34, 111.90, 115.36, 118.14, 130.13, 133.01, 134.58, 134.64, 16359, 194.80

IR ($CHCl_3$): 3019, 2240, 1684, 1500, 1360, 1280, 1139, 1124 cm^{-1}

MS (m/e): 215 (M^+), 214, 200, 187, 172, 146, 118, 101, 90, 77, 63, 55 (base), 43

Hi-Res MS: $C_{13}H_{13}NO_2$, Calculated: 215.0946, Found 215.0945

4-(3-Buten-1-oxy)-3-methylacetophenone (m-Me-pBA):



2-Methyl-phenylacetate:

Acetyl chloride (38 ml, 0.56 mol) was added dropwise to ice cooled solution of *o*-cresol (50 ml, 0.49 mol) and pyridine (55 ml, 0.68 mol) in 100 ml of dry benzene. The solution was stirred during the addition while temperature was mentained below 20°C. The solution was left stirring at room temperature overnight, water was added and the organic layer was isolated. The aqueous layer was extracted twice with ether. The combined organic layers were washed with 10% HCl (2X), water, then with 10% sodium hydroxide solution. After drying over anhydrous magnesium sulfate, the solvent was removed by the rotary evaporator . Vacuum distillation (90°C/asp) gave 61 g (84.7%) of pure product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.17 (s, 3H), 2.3 (s, 3H), 6.98 (dd, J = 7.97, 1.65 Hz, 1H), 7.1-7.3 (m, 3H)

4-Hydroxy-3-methylacetophenone:

Anhydrous aluminum chloride (10.0 g, 0.075 mol) was stirred in dry nitrobenzene at 70°C under argon atmosphere until all the solid dissolved. The solution was cooled to about 10°C and *o*-methyl-phenyl acetate (10.0 g, 0.067 mol) was added dropwise in such a rate that the temperature did not exceed 20°C. The mixture was left stirring at room temperature overnight. 10% HCl was added, and the mixture was stirred for 10 minutes. The mixture was cooled and extracted with ether. The product was extracted with 10% sodium hydroxide solution several times (until the aqueous layer was colorless). The combined aqueous layers were acidified with 10% HCl to give the free phenolic product which was extracted into ethylacetate. The organic layer was washed with water then with sodium bicarbonate solution, and dried over magnesium sulfate. The solvent was removed using a rotary evaporator to give a yellowish solid which

was recrystallized from benzene then vacuum distilled (kugelrohr) to give 5.2 g (52%) of pure product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.28 (s, 3H), 2.54 (s, 3H), 6.1 (broad, s, 1H), 6.83 (d, J = 8.24 Hz, 1H), 7.74 (dd, J = 8.24, 2.19 Hz, 1H), 7.77 (broad, m, 1H)

m-Me-pBA:

4-Bromo-1-butene (4 g, 0.03 mol) was added to a mixture of 4-hydroxy-3-methylacetophenone (3.0 g, 0.02 mol) and anhydrous potassium carbonate (4.0 g, 0.029 mol) in 30 ml of dry DMF. The mixture was stirred at room temperature for one week under an argon atmosphere, water was added, and the product was extracted with diethyl ether. The organic layer was washed with 10% sodium hydroxide solution 4 times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford 1.8 g of a yellowish oil which was purified by vacuum distillation using a kugelrohr to give 1.3 g (32%) of pure product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.22 (s, 3H), 2.52 (s, 3H), 2.56 (tq, J = 1.29, 6.6 Hz, 2H), 4.06 (t, J = 6.58 Hz, 2H), 5.01 (ddt, J = 10.2, 1.8, 1.13 Hz, 1H), 5.16 (dq, J = 17.12, 1.6 Hz, 1H), 5.81 (ddt, J = 17.12, 10.29, 6.78 Hz, 1H), 6.8 (d, J = 8.24 Hz, 1H), 7.75 (d, J = 2.23 Hz, 1H), 7.78 (dd, J = 8.24, 2.23 Hz, 1H)

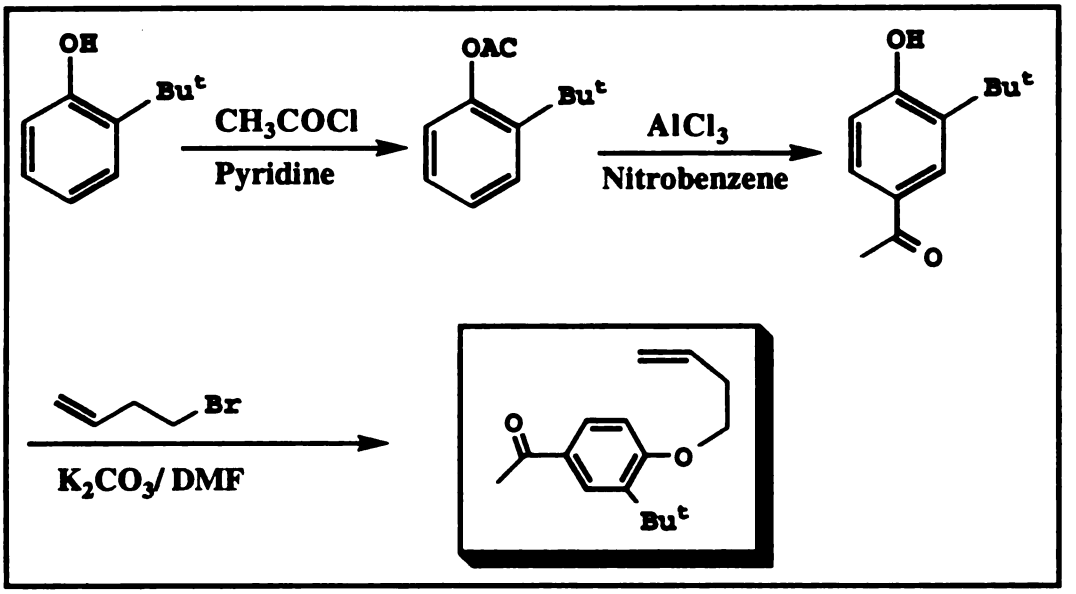
^{13}C NMR ($CDCl_3$) (75 MHz): δ 16.02, 26.08, 33.40, 67.14, 109.74, 117.05, 126.67, 128.25, 129.55, 130.67, 134.04, 160.87, 196.83

IR ($CHCl_3$): 3009, 2928, 1671, 1601, 1503, 1360, 1265, 1144, 1132, 1030 cm^{-1}

MS (m/e): 204 (M^+), 189, 176, 161, 150, 135, 121, 107, 91, 77, 55 (base), 43

Hi-Res MS: $C_{13}H_{16}O_2$, Calculated: 204.1150, Found 204.1138

4-(3-Buten-1-oxy)-3-*t*-butylacetophenone (m-^{t}Bu-pBA):



2-*t*-Butyl-phenylacetate:

Acetyl chloride (27 ml, 0.40 mol) was added dropwise to ice cooled solution of *o*-*t*-butyl phenol (50 ml, 0.34 mol) and pyridine (40.0 ml, 0.50 mol) in 100 ml of dry benzene. The reaction was carried on following the procedure of 2-methyl-phenylacetate. Vacuum distillation (110°C/asp) gave 61 g (95%) of pure product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.36 (s, 9H), 2.33 (s, 3H), 6.98 (dd, J = 1.74, 7.63 Hz, 1H), 7.15 (dt, J = 1.73, 7.49 Hz, 1H), 7.21 (dt, J = 1.9, 7.49 Hz, 1H), 7.38 (dd, J = 7.66, 1.95 Hz, 1H)

3-*t*-Butyl-4-hydroxyphenol:

Anhydrous aluminum chloride (2.2 g, 0.017 mol) was stirred in 10 ml dry nitrobenzene at 70°C under argon atmosphere until all the solid dissolved. The solution was cooled to about 10°C and *o*-*t*-butyl-phenylacetate (2.6 g, 0.014 mol) was added dropwise in such a rate that the temperature did not exceed 20°C. The mixture was left stirring at room temperature overnight. It was worked up in the same manner as 4-hydroxy-3-methylacetophenone. The resulting solid was recrystallized from benzene/hexanes to give 1.0 g (38%) of white crystals, mp: 167-170°C.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.42 (s, 9H), 2.54 (s, 3H), 5.4 (s, broad, 1H), 6.72 (d, J = 8.27 Hz, 1H), 7.71 (dd, J = 8.27, 2.2 Hz, 1H), 7.94 (d, J = 2.2 Hz, 1H)

m-^{t}Bu-pBA:

4-Bromo-1-butene (3.0 g, 0.022 mol) was added to a mixture of 3-*t*-butyl-4-hydroxyacetophenone (1.90 g, 0.01 mol) and anhydrous potassium carbonate (2.5 g, 0.018 mol) in 30 ml of dry DMF. The mixture was stirred at room temperature for 4 days under an argon atmosphere, water was added and the product was extracted with diethyl ether. The organic layer was washed with 10% sodium hydroxide solution 4 times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford a yellowish oil which was purified by vacuum distillation using kugelrohr to give 0.6 g (24.7%) of pure product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.41 (s, 9H), 2.56 (s, 3H), 2.64 (tq, J = 1.2, 6.59 Hz, 2H), 4.13 (t, J = 6.49 Hz, 2H), 5.15 (ddt, J = 10.2, 1.74, 1.19 Hz, 1H), 5.22 (dq, J

= 17.15, 1.16 Hz, 1H), 5.95 (ddt, J = 17.09, 10.29, 6.72 Hz, 1H), 6.88 (d, J = 8.61 Hz, 1H), 7.82 (dd, J = 2.35, 8.55 Hz, 1H), 7.96 (d, J = 2.23 Hz, 1H)

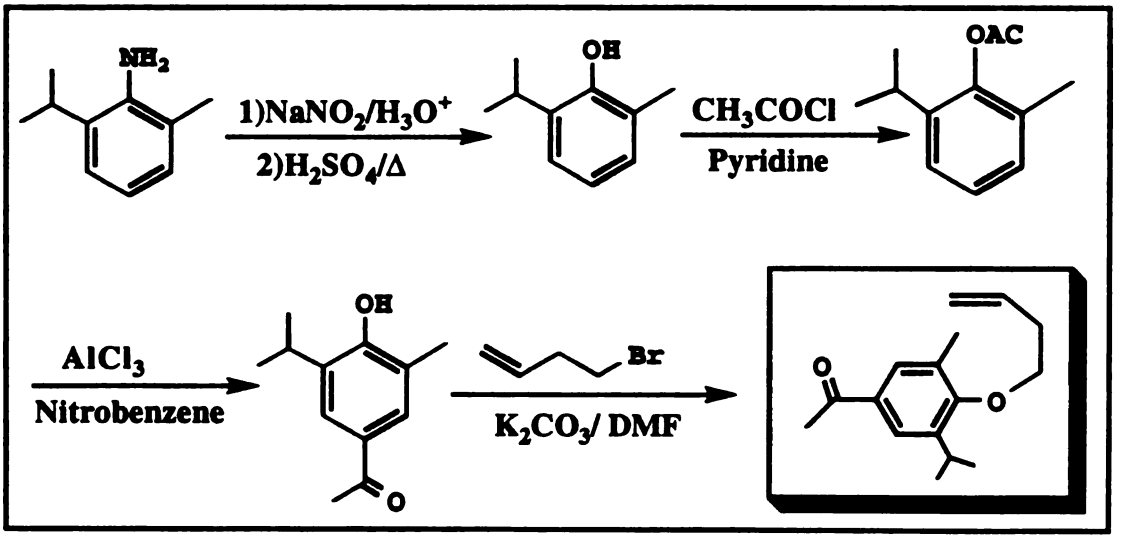
^{13}C NMR ($CDCl_3$) (75 MHz): δ 26.28, 29.59, 33.74, 34.97, 67.48, 110.96, 117.45, 127.13, 128.62, 129.59, 134.41, 138.05, 161.7, 197.22

IR ($CHCl_3$): 3005, 2961, 2873, 1672, 1595, 1468, 1360, 1269, 1242, 1163, 1090, 1026 cm^{-1}

MS (m/e): 246 (M^+), 231, 189, 177, 161, 149, 133, 115, 91, 77, 55 (base), 43

Hi-Res MS: $C_{16}H_{22}O_2$, Calculated: 246.1620, Found 246.1615

4-(3-Buten-1-oxy)-3-isopropyl-5-methylacetophenone (m-Me-^{i}Pr-pBA):



2-Isopropyl-6-methyl phenol:

2-Isopropyl-6-methyl aniline (Aldrich) (9.33 g, 0.063 mol) was dissolved in a mixture of 11 ml of concentrated sulfuric acid and 50 ml of water. The

solution was cooled to -5°C and diazotized by adding ice cooled solution of sodium nitrite (4.44g, 0.064 mol) in 10 ml of water in such a rate that temperature did not exceed 0°C (about 30 min.). The solution was left for 10 minutes at -5°C, then added to a solution of 50 ml of concentrated sulfuric acid and 50 ml water. Nitrogen gas started to evolve immediately and the solution was warmed to 50°C and left for 30 minutes. The reaction mixture was steam distilled. The distillate was extracted with diethyl ether. The organic layer was dried over magnesium sulfate and solvent was removed to give 5.5 g of product which was vacuum distilled (kugelrohr) or (109-111°C/asp) to give 5.36 g (60%) of the product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.24 (d, *J* = 6.87 Hz, 6H), 2.24 (s, 3H), 3.18 (septet, *J* = 6.87 Hz, 1H), 4.63 (s, broad, 1H), 6.82 (t, *J* = 7.63 Hz, 1H), 6.96 (d of quintet, *J* = 7.43, 0.86 Hz, 1H), 7.05 (dt, *J* = 7.69, 0.82 Hz, 1H),.

2-Isopropyl-6-methyl-phenylacetate:

Acetyl chloride (3.4 ml, 0.05 mol) was added dropwise to ice cooled solution of 2-isopropyl-6-methyl phenol (5.0 g, 0.033 mol) and pyridine (5.4 ml, 0.067 mol) in 50 ml of dry benzene. The reaction was carried on as in o-acetoxy toluene. Vacuum distillation (123°C/asp) gave 5.83 g of pure product.

^{1}H NMR ($CDCl_3$): δ 1.19 (d, *J* = 7.07 Hz, 6H), 2.13 (s, 3H), 2.33 (s, 3H), 2.95 (septet, *J* = 7.07 Hz, 1H), 7.05 (ddd, *J* = 7.07, 1.76, 0.66 Hz, 1H), 7.11 (dd, *J* = 7.74, 7.07 Hz, 1H), 7.14 (dd, *J* = 7.73, 1.98 Hz, 1H),.

4-Hydroxy-3-Isopropyl-5-methylacetophenone:

Anhydrous aluminum chloride (2.0 g, 0.015 mol) was stirred in 10 ml dry nitrobenzene at 70°C under argon atmosphere until all the solid dissolved. The

solution was cooled to about 10°C and 2-isopropyl-6-methyl acetoxy benzene (2. g, 0.01 mol) was added dropwise at such a rate that the temperature did not exceed 20°C. Then it was left stirring at room temperature for 6 days. The mixture was worked up as with 4-hydroxy-3-methylacetophenone. The resulting solid was recrystallized from benzene/hexanes to give 1.50 g (75%) of white crystals, mp: 111- 112°C.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.37 (d, J = 6.85 Hz, 6H), 2.28 (s, 3H), 2.53 (s, 3H), 3.18 (septet, J = 6.85 Hz, 1H), 5.2 (broad, s, 1H), 7.61 (dd, J = 2.21, 0.88 Hz, 1H), 7.71 (d, J = 2.21 Hz, 1H)

m-Me-^{i}Pr-pBA:

4-Bromo-1-butene (2.0 g, 0.015 mol) was added to a mixture of 2-isopropyl-6-methyl acetoxy benzene..(1.4 g, 0.0073 mol) and anhydrous potassium carbonate (2.0g, 0.014 mol) in 30 ml of dry DMF. The mixture was stirred at room temperature for 10 days under argon atmosphere. Then it was worked up following the procedure of 4-(3-buten-1-oxy)-3-methylacetophenone to give a yellowish oil which was purified by vacuum distillation using a kugelrohr to give 0.9 g (50%) of the product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.22 (d, J = 6.93 Hz, 6H), 2.31 (s, 3H), 2.54 (s, 3H), 2.57 (tq, J = 1.34, 6.69 Hz, 2H), 3.31 (septet, J = 6.89 Hz, 1H), 3.81 (t, J = 6.68 Hz, 2 H), 5.12 (ddt, J = 10.23, 1.8, 1.19 Hz, 1H), 5.18 (dq, J = 17.16, 1.7 Hz, 1H), 5.94 (ddt, J = 17.12, 10.29, 6.78 Hz, 1H), 7.61 (dd, J = 2.26, 0.76 Hz, 1H), 7.71 (d, 2.2 Hz, 1H)

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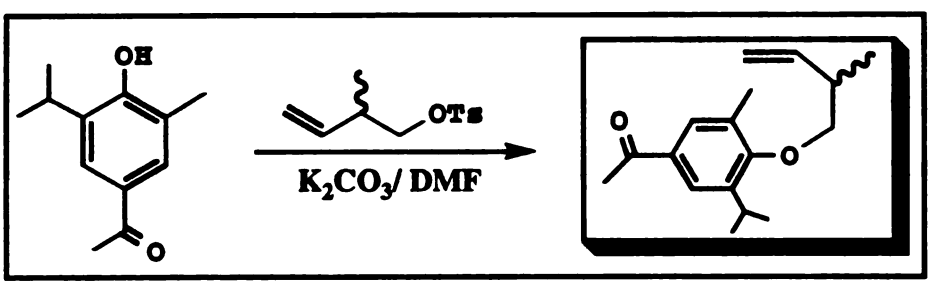
^{13}C NMR ($CDCl_3$) (75 MHz): δ 16.74, 23.74, 26.50, 34.72, 72.59, 117.22, 124.83, 129.24, 131.21, 133.21, 134.41, 142.14, 159.04, 197.69

IR ($CHCl_3$): 3020, 2969, 2932, 2875, 1677, 1361, 1308, 1281, 1185 cm^{-1}

MS (m/e): 246 (M^+), 231, 191, 177, 161, 147, 129, 112, 91, 77, 70, 55 (base), 43

Hi-Res MS: $C_{16}H_{22}O_2$, Calculated: 246.1620, Found 246.1606

4-(2-Methyl-3-buten-1-oxy)-3-isopropyl-5-methylacetophenone (m-Me-^{i}Pr-Me2-pBA):



2-Methyl-3-butenyl-1-tosylate:

2-Methyl-3-butene-1-ol (Aldrich) (1.0 g, 0.0116 mol) was dissolved in pyridine (2 ml, 0.025 mol). The solution was cooled in ice bath and *p*-toluenesulfonyl chloride (2.4 g, 0.0126 mol) was added in portions. After addition was complete, the mixture was left at room temperature overnight. Water was added and the solution was extracted with ether. The ether layer was washed with dilute sulfuric acid then with 10% sodium hydroxide solution, dried over magnesium sulfate and evaporated to give 2.1 g (92%) of the product which was used in the next step without further purification.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 0.98 (d, J = 6.83 Hz, 3H), 2.43 (s, 3H), 2.49 (t of septet, J = 1.16, 6.72 Hz, 1H), 3.82 (dd, J = 9.43, 6.87 Hz, 1H), 3.9 (dd, J = 9.40, 6.38 Hz, 1H), 5.01 (dt, J = 10.59, 1.31 Hz, 1H), 5.02 (dt, J = 17.0, 1.38 Hz, 1H), 5.61 (ddd, J = 17.24, 10.69, 7.02 Hz, 1H), 7.32 (d, J = 8.20 Hz, 2H), 7.77 (d, J = 8.44 Hz, 2H)

m-Me-^{i}Pr-Me_2-pBA:

2-Methyl-3-butenyl-1-tosylate (1.0 g, 0.0042 mol) was added to a mixture of 4-hydroxy-3-isopropyl-5-methylacetophenone (0.8 g, 0.0042 mol) and anhydrous potassium carbonate (1.00 g, 0.0072 mol) in 10 ml of dry DMF. The mixture was stirred at room temperature for one week under an argon atmosphere, water was added and the product was extracted with diethyl ether. The organic layer was washed with 10% sodium hydroxide solution 4 times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford yellowish oil which was purified by vacuum distillation using a kugelrohr to give 0.58 g (46%) of the product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.19 (d, J = 6.81 Hz, 3H), 1.22 (d, J = 6.9 Hz, 6H), 2.33 (s, 3H), 2.54 (s, 3H), 2.7 (broad septet, J = 6.65 Hz, 1H), 3.3 (septet, J = 6.87 Hz, 1H), 3.6 (dd, J = 8.76, 6.56 Hz, 1H), 3.66 (dd, J = 8.76, 6.29 Hz, 1H), 5.09 (dt, J = 10.32, 1.36 Hz, 1H), 5.15 (dt, J = 17.31, 1.52 Hz, 1H), 5.91 (ddd, J = 17.38, 10.38, 6.96 Hz, 1H), 7.60 (dd, J = 2.25, 0.71 Hz, 1H), 7.71 (d, J = 2.38 Hz, 1H)

^{13}C NMR ($CDCl_3$) (75 MHz): δ 16.40, 16.64, 23.60, 26.34, 26.39, 38.44, 77.43, 114.71, 124.72, 129.19, 131.10, 133.15, 140.28, 142.02, 158.93, 197.41

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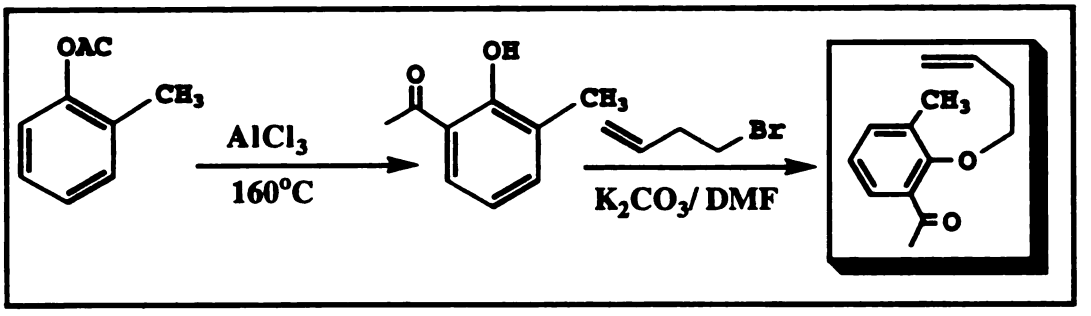
IR ($CHCl_3$): 3009, 2967, 2930, 2872, 1676, 1597, 1462, 1420, 1358, 1306, 1279, 1186, 1007, 920 cm^{-1}

MS (m/e): 260 (M^+), 192, 177 (base), 161, 149, 129, 105, 91, 77, 69, 55, 43, 41

Hi-Res MS: $C_{17}H_{24}O_2$, Calculated: 260.1776, Found 260.1793

2-(3-Buten-1-oxy)-3-methylacetophenone (m-Me-oBA):



2-Hydroxy-3-methylacetophenone:

2-Methyl-phenyl acetate (30.0 g, 0.20 mol) and anhydrous aluminum chloride (30.0 g, 0.23 mol) were stirred together at 150°C under an argon atmosphere for 2 hours after which the reaction mixture became a black solid. After cooling, dilute HCl was added and the mixture was boiled until the solid dissolved. The resulting solution was steam distilled. The distillate was extracted with ether. The organic layer was dried over magnesium sulfate and the solvent was removed using a rotary evaporator. The crude was vacuum distilled (116°C/asp) to give 6.0 g (20%) of product.

^1H NMR ($CDCl_3$) (300 MHz): δ 2.24 (s, 3H), 2.61 (s, 3H), 6.79 (t, J = 7.68, Hz, 1H), 7.35 (d, J = 7.2 Hz, 1H), 7.6 (dd, J = 7.96, 1.09 Hz, 1H), 12 55 (s, 1H)

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m-Me-oBA:

4-Bromo-1-butene (8.0 g, 0.06 mol) was added to a mixture of 2-hydroxy-3-methylacetophenone (5.0 g, 0.033 mol), potassium *t*-butoxide (3.74 g, 0.033 mol) and anhydrous potassium carbonate (5.0 g, 0.036 mol) in 50 ml of dry DMF. The mixture was stirred at room temperature for 8 days under an argon atmosphere, water was added and the product was extracted with diethyl ether. The organic layer was washed with 10% sodium hydroxide solution 4 times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator. The crude product was filtered through a short silica gel column (prep TLC type, hexane). Solvent was evaporated and product was vacuum distilled (kugelrohr) to give 1.5 g (22%) of product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.29 (s, 3H), 2.52 (tq, J = 1.33, 6.8 Hz, 2H), 2.60 (s, 3H), 3.81 (t, J = 6.75 Hz, 2H), 5.09 (ddt, J = 10.2, 1.8, 1.19 Hz, 1H), 5.15 (dq, 17.24, 1 1.62 Hz, 1H), 5.88 (ddt, J = 10.28, 17.15, 6.81 Hz, 1H), 7.04 (t, J = 7.58 Hz 1H), 7.29 (ddd, J = 7.45, 1.04, 0.67 Hz, 1H), 7.37 (ddd, J = 7.66, 0.65, 1.7 Hz, 1H)

^{13}C NMR ($CDCl_3$) (75 MHz): δ 16.13, 30.54, 34.58, 74.12, 117.28, 123.84, 127.18, 132.17, 133.94, 134.22, 134.66, 156.17, 201.50

IR ($CHCl_3$): 3009, 2920, 1684, 1588, 1464, 1431, 1379, 1358, 1281, 1260, 990 cm^{-1}

MS (m/e): 204 (M^+), 189, 176, 163, 150, 136 (base), 129, 121, 105, 91, 77, 55, 43

Hi-Res MS: $C_{13}H_{16}O_2$, Calculated: 204.1150, Found 204.1141

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Ac

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coo

wa

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^1H

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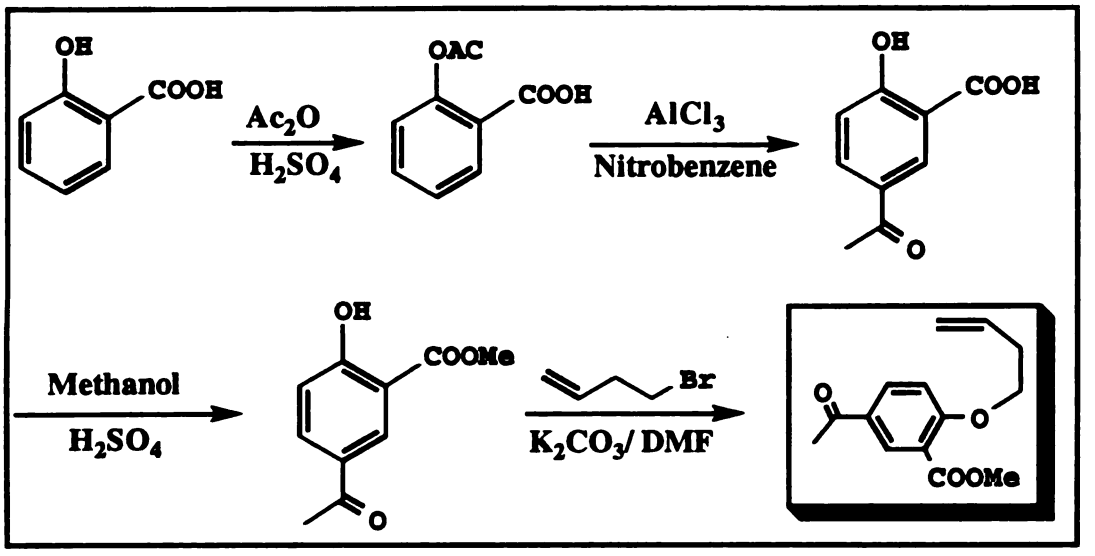
7.9

5-A

Sha

nitr

Methyl-5-acetyl-2-(3-buten-1-oxy) benzoate (m-Est-pBA):



Acetyl salicylic acid (aspirin):[109]

Salicylic acid (30.0 g,0.22 mol), acetic anhydride (42 ml, 0..44 mol) and concentrated sulfuric acid (15 drops) were stirred at 60°C for 30 minutes. After cooling water was added, the formed precipitate was filtered, washed with cold water and recrystallized from a mixture of 90 ml ethanol and 225 ml water to give 30.6 g (78.8%) of aspirin, mp: 137-139°C.

^{1}H NMR (CDCl3) (300 MHz): δ 2.33 (s, 3H), 7.12 (dd, J = 1.09, 8.02 Hz, 1H), 7.34 (dt, J = 1.13, 7.75 Hz, 1H), 7.61 (dt, J = 1.67, 7.84 Hz, 1H), 8.1 (dd, J = 1.85, 7.94 Hz, 1H)

5-Acetyl-2-hydroxy-benzoic acid

The title compound was prepared according to the procedure of Shah.[110]Anhydrous aluminum chloride (52.0 g, 0.39 mol) was stirred in dry nitrobenzene at 70°C under an argon atmosphere until all the solid dissolved.

The solution was cooled to about 10°C and aspirin (15.0 g, 0.083 mol) was added in portions a rate that the temperature did not exceed 20°C. The mixture was left stirring at room temperature for 3 hours, 10% HCl was added, stirred for 20 minutes. Nitrobenzene was removed by steam distillation, the product was collected by suction filtration and recrystallized from ethanol/water (40:60) to give 7.7 g (51%) of white needles of the product (mp: 216-217°C)

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.63 (broad. s, 1H), 2.57 (s, 3H), 7.05 (d, J = 8.85 Hz, 1H), 8.13 (dd, J = 2.29, 8.91 Hz, 1H), 8.52 (d, J = 2.6 Hz, 1H), 11.02 (s, 1H)

Methyl-(5-acetyl-2-hydroxy) benzoate:

5-Acetyl-2-hydroxy benzoic acid (7.0 g, 0.039 mol), methanol (80 ml) and concentrated sulfuric acid (1.0 ml) were boiled for six hours. Solvent was removed and the residue was dissolved in ethylacetate, washed with sodium bicarbonate solution, and dried over magnesium sulfate. After removing the ethyl acetate a yellow solid was left which was purified by passage through a short column of basic alumina using ethyl acetate/hexanes as eluent to finally give 4.5 g of product which was further purified by vacuum distillation (kugelrohr) to give 4.3 g (61 %) of white solid, mp: 62-64°C

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.56 (s, 3H), 3.98 (s ,3H), 7.02 (d, J = 8.79 Hz, 1H), 8.07 (dd, J = 2.23, 8.79 Hz, 1H), 8.49 (d, J = 2.41 Hz, 1H), 11.22 (s, 1H)

m-Est-pBA

4-Bromo-1-butene (2.7 g, 0.02 mol) was added to a mixture of methyl-(5-acetyl-2-hydroxy) benzoate (3.10 g, 0.016 mol) and anhydrous potassium carbonate (2.80 g, 0.02 mol) in 30 ml of dry DMF. The mixture was stirred at room

temperature for 4 days. The reaction mixture was then worked up following the procedure of 4-(3-buten-1-oxy)acetophenone to give an oil which was purified by vacuum distillation using a kugelrohr to give 0.2 g (5%) of the product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.57 (s, 3H), 2.61 (qt, *J* = 6.81,1.17 Hz, 2H), 3.9 (s, 3H), 4.15 (t, *J* = 6.62 Hz, 2H), 5.13 (dq, *J* = 10.19, 1.13 Hz, 1H), 5.19 (dq, *J* = 17.22, 1.62 Hz, 1H), 5.93 (ddt, *J* = 10.29, 17.18, 6.77 Hz, 1H), 7.00 (d, *J* = 8.85 Hz, 1H), 8.08 (dd, *J* = 2.35, 8.79 Hz, 1H), 8.38 (d, *J* = 2.28 Hz, 1H),.

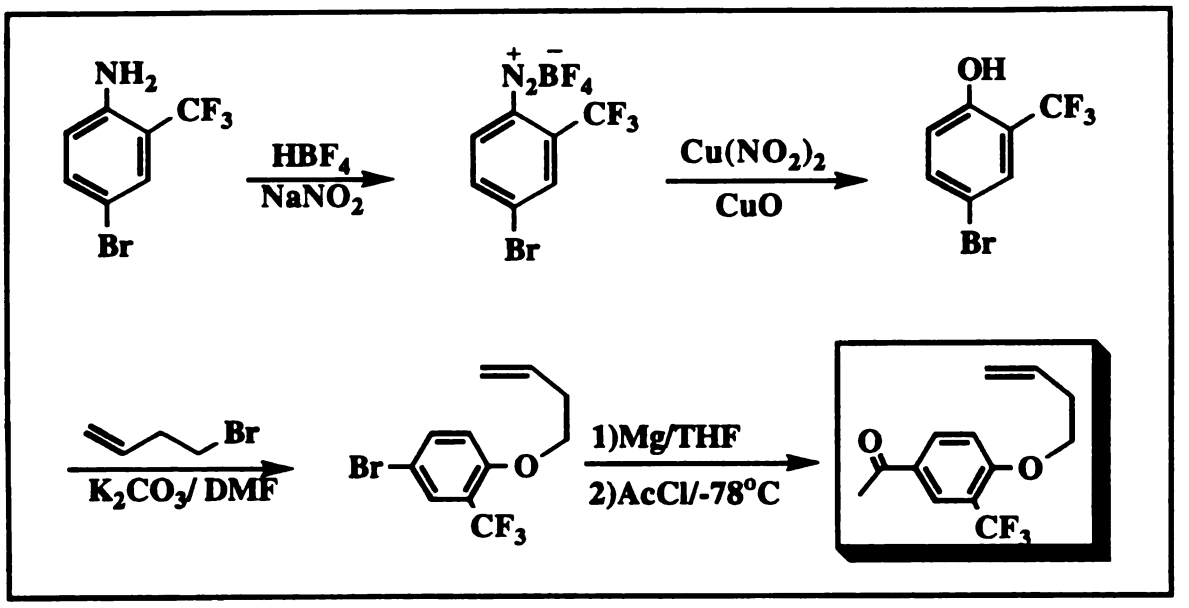
^{13}C NMR ($CDCl_3$) (75 MHz): δ 26.17, 33.26, 51.96, 68.28, 112.47, 117.35 119.99, 129.34, 132.50, 133.44, 133.68, 161.71, 165.88, 195.87

IR ($CHCl_3$): 3012, 2953, 1727, 1680, 1605, 1501, 1439, 1362, 1271, 1154, 1100, 1078 cm^{-1}

MS (m/e): 248 (M^+), 217, 207, 194, 179, 162, 147, 119, 91, 79, 63, 55 (base), 45

Hi-Res MS: $C_{14}H_{16}O_4$, Calculated: 248.1049, Found 248.1053

4-(3-Buten-1-oxy)-3-trifluoromethylacetophenone (m-CF_3-pBA):



4-Bromo-2-(α,α,α–trifluoromethyl) benzene-diazonium tetrafluoroborate.

4-Bromo-α,α,α-trifluoro-*o*-toluidine was diazotized using a general procedure[111]. Fluoroboric acid (48%, 30 ml) was added to 4-bromo-α,α,α-trifluoro-*o*-toluidine (2.4 g,0.01 mol) in 40 ml of water. The resulting solution was cooled to 5°C and a solution of sodium nitrite (0.71g, 0.01 mol) in water (2.5 ml) was added dropwise. the solution was cooled to 0°C. The formed solid was collected by filtration, washed with ice-cold 10% fluoroboric acid, ice-cold 2-propanol, and ether to give about 3.0 g of wet product.

4-Bromo-α,α,α-trifluoro-o-cresol:

The diazonium salt was hydrolyzed according to the general procedure of Cohen and coworkers.[112]Copper nitrate (900 g, 4.8 mol) was dissolved in water (600 ml) and the diazonium salt (~3.0 g) was added The solution was stirred until all the salt dissolved. Cuprous oxide (0.60 g) was added and stirring was continued for 3 hours (until solution showed negative azodye test). The solution

was extracted by ethyl acetate. The organic layer was washed with saturated sodium chloride solution, dried over magnesium sulfate, and evaporated to give ~2.0 g of crude product which was vacuum distilled (kugelrohr) to give 1.73g (72%) of the product, mp 83-84°C

^{1}H NMR ($CDCl_3$) (300 MHz): δ 5.5 (q, *J* = 2.05 Hz, 1H), 6.84 (d, *J* = 8.28 Hz, 1H), 7.5 (dd, *J* = 1.95, 8.76 Hz, 1H), 7.6 (d, *J* = 2.41 Hz, 1H)

5-Bromo-2-(3-buten-1-oxy)-α,α,α-trifluorotoluene:

4-Bromo-1-butene (4 g, 0.03 mol) was added to a mixture of 4-bromo-α,α,α-trifluoro-*o*-cresol(1.5 g, 0.006 mol) and anhydrous potassium carbonate (1.5 g, 0.011 mol) in 30 ml of dry DMF. The mixture was stirred at room temperature for 10 days under argon atmosphere, water was added and the product was extracted with diethyl ether. The organic layer was washed with saturated potassium carbonate solution three times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford 1.65 g of product which was purified by column chromatography (silica gel 5% ethylacetate/hexanes). It was further purified by vacuum distillation using kugelrohr to give 1.6 g (87%) of pure product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.55 (tq, *J* = 1.32, 6.68 Hz, 2H), 4.04 (t, *J* = 6.53 Hz, 2H), 5.10 (ddt, *J* = 10.19, 1.8, 1.16 Hz, 1H), 5.15 (dq, *J* = 1718, 1.56 Hz, 1H), 5.88 (ddt, *J* = 10.29, 17.12, 6.77 Hz, 1H), 6.84 (d, *J* = 6.79 Hz, 1H), 7.55 (dd, *J* = 8.82, 2.47 Hz, 1H), 7.65 (d, *J* = 2.48 Hz, 1H)

m-CF_3-pBA

The title compound was prepared from the reaction of Gignard reagent with acetyl chloride according to the general literature procedure in the literature.[113] Magnesium (0.25 g, 0.01 mol), and dry THF (5 ml) were placed in a 250 ml 3-necked rb. flask equipped with dropping funnel. 5-bromo-2-(3-buten-1-oxy)-α,α,α-trifluorotoluene (1.5 g, 0.005 mol) in dry THF (50 ml) was placed in the dropping funnel and added to the magnesium dropwise. The reaction was initiated by adding few drops of 1,2-dibromoethane, then by heating. After addition was complete, the solution was boiled for 2 hours.

In another dry 250 ml 3-necked flask equipped with a dropping funnel and a thermometer, freshly distilled acetyl chloride (1.0 ml, 0.015 mol), and dry THF (15ml) were placed and cooled to -78°C. The Grignard reagent was transferred to the dropping funnel using a canula, and was added dropwise to the acetyl chloride with vigorous stirring while the temperature kept at -78°C. After addition was complete the mixture was mentained at room temperature overnight. The reaction was quenched with water and the product was extracted with ethyl acetate which was then dried over magnesium sulfate, filtered, and evaporated to give the crude product. The product was purified using a dry silica gel column (5% ethyl acetate/ hexanes) to give 0.2 g (mp: 46-49°C), (15.4%) of product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.59 (s, 3H), 2.62 (tq, *J* = 1.25, 6.66 Hz, 2H), 4.18 (t, *J* = 6.56 Hz, 2H), 5.14 (ddt, *J* = 10.22, 1.68, 1.16 Hz, 1H), 5.20 (dq, *J* = 17.18, 1.55 Hz, 1H), 5.92 (ddt, *J* = 17.12, 10.25, 6.81 Hz, 1H), 7.04 (d, *J* = 8.79 Hz, 1H), 8.12 (dd, *J* = 2.04, 8.73 Hz, 1H), 8.2 (d, *J* = 1.92 Hz,1H)

13C

Hz)

195

MS

Hi-

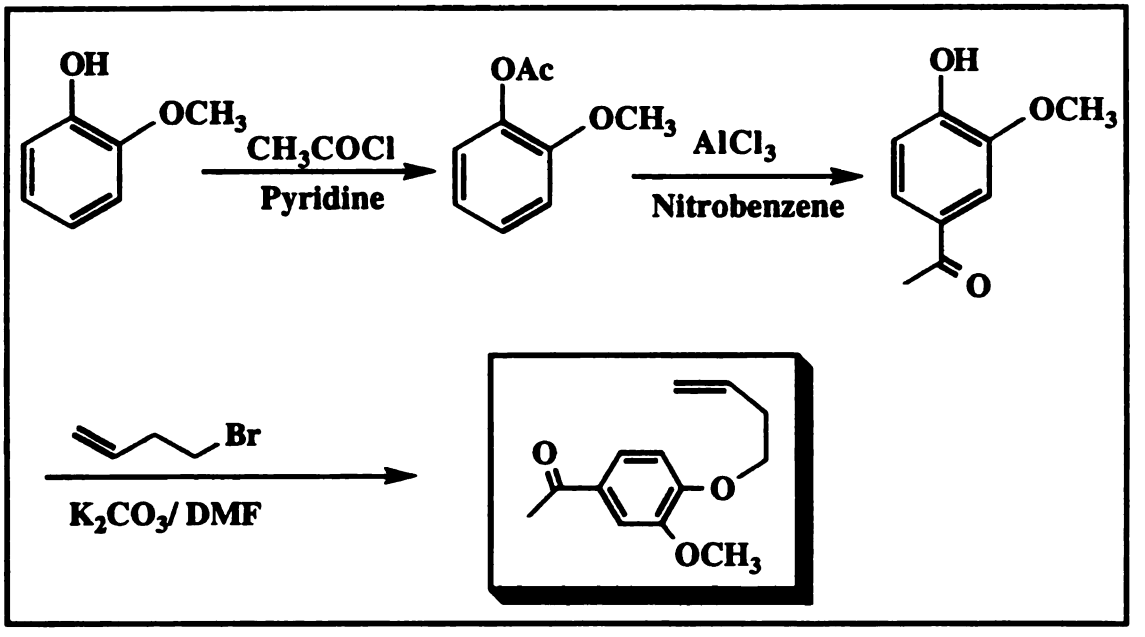
4-(

^{13}C NMR ($CDCl_3$) (75 MHz): δ 2618, 33.20, 68.42, 112.19, 117.2, 118.86 (q, 31.6 Hz), 123.06 (q, 271.1 Hz), 127.86 (q, 5.2 Hz),129.30, 133.42, 133.80, 160.30, 195.59

MS (m/e): 258 (M^+), 230, 215, 204, 189, 169, 160, 144, 127, 113, 55 (base), 43

Hi-Res MS: $C_{13}H_{13}F_3O_2$, Calculated: 258.0868, Found 258.0860

4-(3-Buten-1-oxy)-3-methoxyacetophenone (m-OMe-pBA):



o-Acetoxyanisol (guaiacol acetate):

The title compound was prepared according to the procedure of Mottern.[114]Acetyl chloride (19.0 ml, 0.28 mol) was added dropwise to an ice cooled solution of guaiacol (27.5 ml, 0.25 mol), and pyridine (27.0 ml, 0.34 mol) in 60 ml of dry benzene. The solution was stirred during the addition and the temperature was kept below 20°C. The solution was stirred at room temperature

overnight before water was added and the organic layer was isolated. The aqueous layer was extracted twice with ether The combined organic layers were washed with 10% HCl twice, water, then with 10% sodium hydroxide solution. After drying over anhydrous magnesium sulfate, the solvent was removed by the rotary evaporator . Vacuum distillation (129-131/ asp) gave 38.0 g (92%) of pure product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.3 (s, 3H), 3.82 (s, 3H), 6.9-6.97 (m, 2H), 7.02 (dd, J = 7.72, 1.66 Hz, 1H), 7.19 (ddd, J = 1.65, 8.25, 7.50 Hz, 1H)

4-Hydroxy-3-methoxyacetophenone (apocynin):

Anhydrous aluminum chloride (33.0 g, 0.25 mol) was stirred in dry nitrobenzene (75 ml) at 70°C under an argon atmosphere until all the solid dissolved. The solution was cooled to about 10°C and o-acetoxy anisol (20.0 g, 0.12 mol) was added dropwise in such a rate that the temperature did not exceed 20°C. The mixture was mentained at 80°C for 45 minutes and then stirred at room temperature overnight. 10% HCl was then added, and the mixture was stirred for 10 minutes. The mixture was cooled and extracted with ether. The product was extracted with 10% sodium hydroxide solution several times (until the aqueous layer was colorless). The combined aqueous layers were acidified with 10% HCl to give the free phenolic product which was extracted with ethylacetate. The organic layer was washed with water then with sodium bicarbonate solution, and dried over magnesium sulfate. The solvent was removed using a rotary evaporator to give a yellowish solid which was vacuum distilled (170°C/asp) to give 8.7 g (43.5%) of the product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.56 (s, 3H), 3.95 (s, 3H), 6.12 (broad, s, 1 H), 6.95 (d, J = 8.62 Hz, 1H), 7.53 (dd, J = 1.99, 8.84 Hz, 1H), 7.53 (d, J = 1.76 Hz, 1H)

m-OMe-pBA:

4-Bromo-1-butene (6.0 g, 0.04 mol) was added to a mixture of 4-hydroxy-3-methoxyacetophenone (5.0 g, 0.03 mol) and anhydrous potassium carbonate (6.0 g, 0.044 mol) in 30 ml of dry DMF. The mixture was stirred at room temperature for one week under an argon atmosphere, water was added and the product was extracted with diethyl ether. The organic layer was washed with 10% sodium hydroxide solution four times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford yellowish solid which was purified by vacuum distillation using a kugelrohr to give 4.2g (64%) of white crystals, mp: 56-57°C.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.57 (s, 3H), 2.64 (tq, J = 1.32, 6.96 Hz, 2H), 3.93 (s, 3H), 4.14 (t, J = 7.02 Hz, 2H), 5.14 (ddt, J = 10.19. 1.68, 1.25 Hz, 1H), 5.2(dq, J = 17.15, 1.58 Hz, 1H), 5.92 (ddt, J = 17.15, 10.28, 6.77 Hz, 1H), 6.8 (d, J = 8.18 Hz, 1H), 7.53 (d, J = 1.92 Hz, 1H), 7.56 (dd, J = 8.18, 2.08 Hz, 1H),

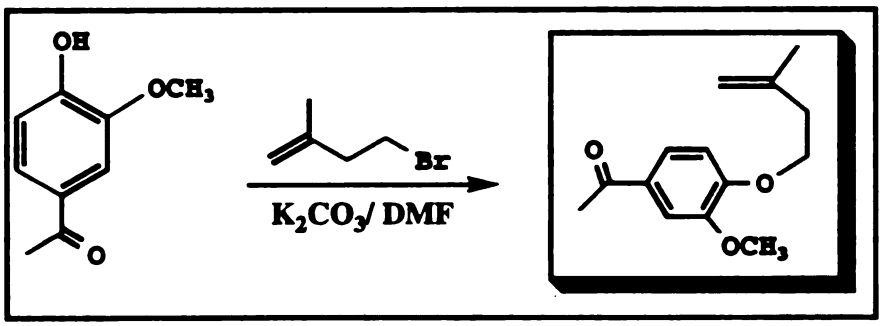
^{13}C NMR ($CDCl_3$)(75 MHz): δ 26.06, 33.34, 55.93, 68.11, 110.18, 111.73, 117.17, 123.21, 130.26, 133.84, 148.11, 153.57, 196.61

IR ($CHCl_3$): 3008, 2940, 1675, 1590, 1514, 1470, 1421, 1361, 1277, 1184, 1157, 1030 cm^{-1}

MS (m/e): 220 (M^+), 192, 166, 151, 123, 108, 91, 79, 65, 55 (base), 43

Hi-Res MS: $C_{13}H_{16}O_3$, Calculated: 220.1099, Found 220.1104

4-(3-Methyl-3-buten-1-oxy)-3-methoxyacetophenone (m-OMe-Me$_3$-pBA):



4-Bromo-2-methyl-1-butene (1.70 g, 0.011 mol) was added to a mixture of 4-hydroxy-3-methoxyacetophenone (1.65 g, 0.01 mol) and anhydrous potassium carbonate (1.60 g, 0.012 mol) in 30 ml of dry DMF. The mixture was stirred at room temperature for 48 hours under an argon atmosphere, water was added and the product was extracted with diethyl ether. The organic layer was washed with 10% sodium hydroxide solution four times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford yellowish oil which was purified by vacuum distillation using kugelrohr to give 1.33 g (57%) the product.

^{1}H NMR($CDCl_3$) (300 MHz): δ 1.8 (t, J = 0.89 Hz, 3H), 2.54 (s, 3H), 2.57 (t, broad, J = 7.42 Hz, 2H), 3.90 (s, 3H), 4.20 (t, J = 7.24 Hz, 2H), 4.79 (m, 1H), 4.82 (m, 1H), 6.87 (d, J = 8.24 Hz, 1H), 7.5 (d, J = 2.02 Hz, 1H), 7.54 (dd, J = 2.04, 8.27 Hz, 1H)

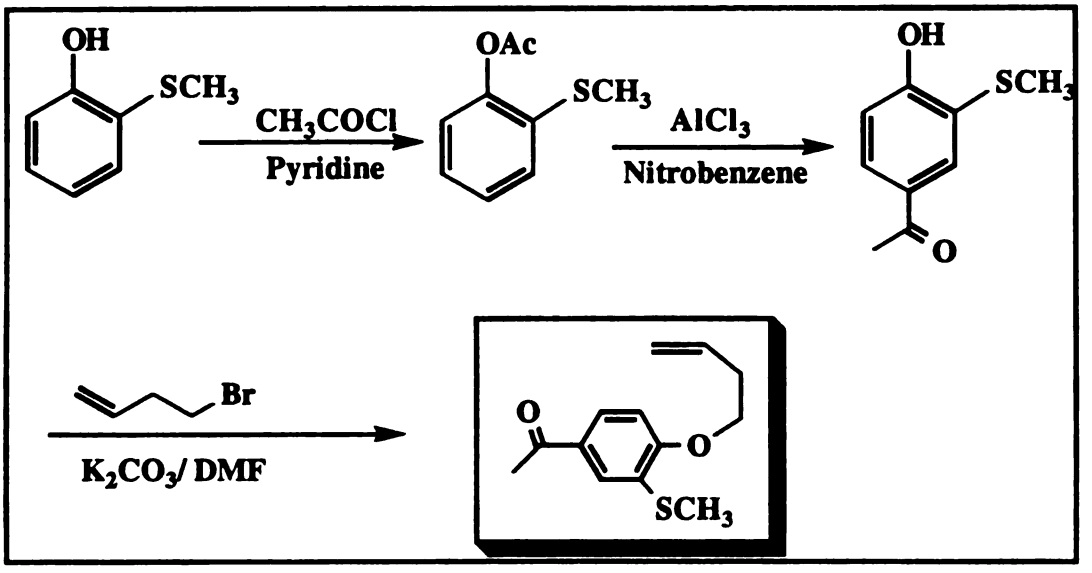
^{13}C NMR ($CDCl_3$) (75 MHz): δ 22.90, 26.18, 36.86, 56.04, 67.58, 110.52, 111.16, 112.34, 123.18, 130.4, 141.63, 149.24, 152.68, 196.77

IR ($CHCl_3$): 3011, 1673, 1588, 1510, 1466, 1418, 1271, 1181, 1150, 1032 cm^{-1}

MS (m/e): 234 (M^+), 166, 151 (base), 135, 123, 91, 77, 69, 55, 43, 41

Hi-Res MS: $C_{14}H_{18}O_3$, Calculated: 234.1256, Found 234.1257

4-(3-Buten-1-oxy)-3-(metylmercapto)acetophenone (m-SMe-pBA):



2-(Methylmercapto)phenylacetate:

Acetyl chloride (2.80 ml, 0.04 mol) was added dropwise to an ice cooled solution of 2-(methylmercapto) phenol (4.81 g, 0.34 mol) and pyridine (3.60 ml, 0.045 mol) in 40 ml of dry benzene. The solution was stirred during the addition and temperature was kept below 20°C. The solution was then stirred at room temperature overnight, water was added and the organic layer was isolated. The aqueous layer was extracted twice with ether. The combined organic layers were washed with 10% HCl twice, water, then with 10% sodium hydroxide solution. After drying over anhydrous magnesium sulfate, the solvent was removed by the

a rotary evaporator . Vacuum distillation (kugelrohr) afforded 5.0 g (92%) of the product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.33 (s, 3H), 2.42 (s, 3H), 7.03 (dd, *J* = 7.42, 1.86 Hz, 1H) 7.14-7.29 (m, 3H),.

4-Hydroxy-3-(methylmercapto)acetophenone:

Anhydrous aluminum chloride (0.90 g, 0.0067. mol) was stirred in dry nitrobenzene at 70°C under argon atmosphere until all the solid dissolved. The solution was cooled to about 10°C and 2-(methylmercapto) phenyl acetate (1.0 g, 0.0055 mol) was added dropwise in such a rate that the temperature did not exceed 20°C. The mixture was kept at room temperature for four days, 10% HCl was then added, stirred for 10 minutes. The mixture was cooled and extracted with ether. The product was extracted with 10% sodium hydroxide solution several times (until the aqueous layer was colorless). The combined aqueous layers were acidified with 10% HCl to give the free phenolic product which was extracted with ether. The organic layer was washed with water then with sodium bicarbonate solution, and dried over magnesium sulfate. The solvent was removed using a rotary evaporator to give a brownish solid which was purified by a flash silica gel column (20% ethyl acetate/hexanes) to give 0.15 g (15%) of pale brown solid, mp: 115-116°C.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.35 (s, 3H), 2.53 (s, 3H), 7.02 (d, *J* = 8.61 Hz, 1H), 7.04 (s, broad, 1H), 7.86 (dd, *J* = 2.2, 8.61 Hz, 1H), 8.14 (d, *J* = 2.21 Hz, 1H)

m-SMe-pBA:

4-Bromo-1-butene (0.1g, 0.75 mmol) was added to a mixture of 4-hydroxy-3-(methylmercapto)acetophenone (0.1 g, 0.55 mmol) and anhydrous potassium carbonate (0.18 g, 1.3 mmol) in 5 ml of dry DMF. The mixture was stirred at room temperature for three days under an argon atmosphere, water was added and the product was extracted with diethyl ether. The organic layer was washed with 10% sodium hydroxide solution four times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford yellowish solid which was purified by vacuum distillation using kugelrohr to give 0.1 g (79%) the product, mp: 35-37°C.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.45 (s, broad, 3H), 2.54 (s, 3H), 2.61 (tq, J = 1.31, 6.75 Hz, 2H), 4.13 (t, J = 6.68 Hz, 2H), 5.12 (ddt, J = 10.19, 1.8, 1.13 Hz, 1H), 5.19 (dq, J = 17.18, Hz, 1H), 5.93 (ddt, J = 17.09, 10.22, 6.81 Hz, 1H), 6.81 (d, J = 8.52 Hz, 1H), 7.72 (dd, J = 2.13, 8.45 Hz, 1H), 7.72 (d, J = 2.01 Hz, 1H)

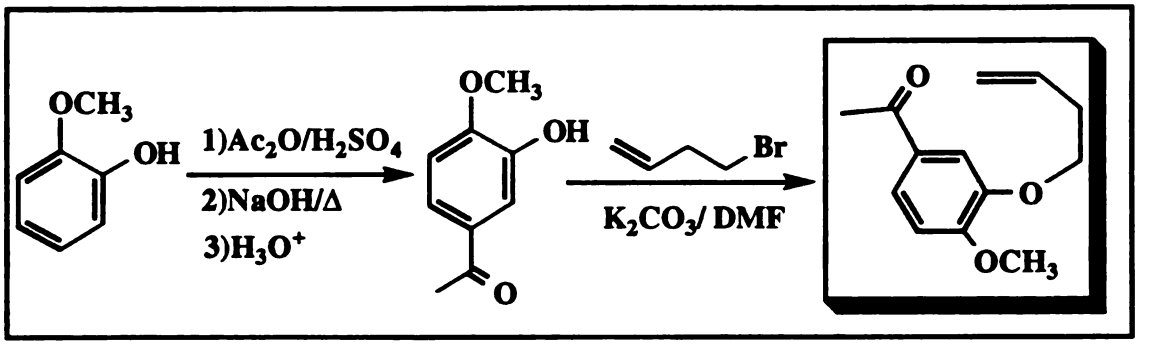
^{13}C NMR ($CDCl_3$) (75 MHz): δ 14.38, 26.27, 33.39, 68.14, 109.73, 117.55, 125.47, 127.28, 128.46, 130.58, 133.86, 159.13, 196.58.

IR ($CHCl_3$): 3005, 2925, 1673, 1584, 1487, 1356, 1256, 1071 cm^{-1}

MS (m/e): 236 (M^+), 221, 195, 182, 167 (base), 149, 139, 121, 111, 95, 77, 69, 55, 43

Hi-Res MS: $C_{13}H_{16}O_2S$, Calculated: 236.0871, Found 236.0862

3-(3-Buten-1-oxy)-4-methoxyacetophenone (p-OMe-mBA):



3-Hydroxy-4-methoxyacetophenone:

The title compound was prepared according the published procedure.[115] Concentrated sulfuric acid (25 ml) was added carefully to a well stirred mixture of guaiacol (25.0 g, 0.20 mol) and acetic anhydride (175.0 ml). The mixture was cooled during the addition (water bath) so that the temperature did not exceed 80°C. It was then stirred at room temperature for 24 hours before 1.5 liter of water was added, and the reaction stirred for 30 minutes. The mixture was extracted with ether and washed with water. After evaporation of the ether, the oily dark brown residue was boiled with 10% sodium hydroxide (some ethanol was added) for 2 hours, then the reaction was cooled, acidified and extracted with ether. The ether layer was washed with water, and sodium bicarbonate solution, then dried over anhydrous magnesium sulfate, and evaporated to give 11.0 g of a sticky brown oil. This oil was stirred with chloroform, filtered and evaporated to give 8.0 g of a solid which was filtered, through short column of silica gel using methylene chloride as eluent. Vacuum distillation (kugelrohr) followed by crystallization from benzene gave 4.0 g (12%) of pure product.(mp: 89-91°C)

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.51 (s, 3H), 3.93 (s, 3H), 5.75 (broad, s, 1H), 6.86 (d, J = 9.04 Hz, 1H), 7.51 (d, J = 1.86 Hz, 1H), 7.52 (dd, J = 2.17, 9.1 Hz, 1H)

p-OMe-mBA:

4-Bromo-1-butene (5.0 g, 0.037 mol) was added to a mixture of 3-hydroxy-4-methoxyacetophenone (3.4 g, 0.02 mol), anhydrous potassium carbonate (3.5 g, 0.025 mol), and potassium-*t*-butoxide (2.3 g, 0.02 mol) in 30 ml of dry DMF. The mixture was stirred at room temperature for one week under argon atmosphere, water was added and the product was extracted with diethyl ether. The organic layer was washed with 10% sodium hydroxide solution four times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford a solid which was purified by vacuum distillation using kugelrohr to give 2.1 g (47%) of pure 3-(3-buten-1-oxy)-4-methoxyacetophenone (mp: 48-49°C)

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.55 (s, 3H), 2.61 (tq, J = 1.22, 6.93 Hz, 2H), 3.92 (s, 3H), 4.11 (t, J = 6.93 Hz, 2H), 5.11 (ddt, J = 10.19, 1.6 , 1.15 Hz, 1H), 5.18 (dq, 17.24, 1.65 Hz, 1H), 5.91 (ddt, J = 10.22, 17.06, 6.81 Hz, 1H), 6.88 (d, J = 8.31 Hz, 1H), 7.52 (d, J = 2.02 Hz, 1H), 7.57 (dd, J = 2.07, 8.27 Hz, 1H)

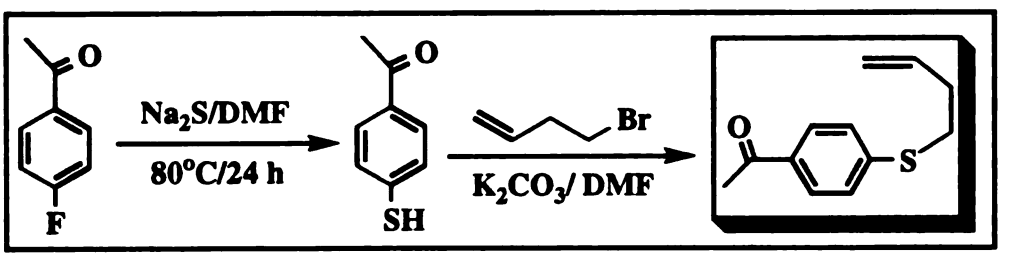
^{13}C NMR ($CDCl_3$) (75 MHz): δ 26.1, 33.3, 55.9, 68.0, 110.4, 111.1, 117.4, 123.1, 130.3, 133.6, 149.1, 152.6, 196.6

IR ($CHCl_3$): 3009, 1673, 1588, 1512, 1427, 1358, 1269, 1181, 1148, 1024 cm^{-1}

MS (m/e): 220 (M^+), 205, 192, 177, 166, 151, 137, 123, 109, 91, 79, 65, 55 (base), 43

Hi-Res MS: $C_{13}H_{16}O_3$, Calculated: 220.1099, Found 220.1096

4-(3-Buten-1-mercapto)acetophenone (p-Thio-AP):



4-Mercaptoacteophenone:

Hydrated sodium sulfide ($Na_2S{\cdot}9H_2O$), (90.0 G, 0.375 mol) was dried by heating at 100°C under vacuum (rotary evaporator) until no water distilled, then under high vacuum for 2 hours. 4-Fluoroacetophenone (5.2 g, 0.038 mol), and DMF were added and the mixture was heated overnight at 80°C, before being cooled, and quenched by the addition of ice and water. The resulting solution was acidified with HCl(**CAUTION**: a considerable amount of H_2S gas was evolved with foaming). The acid was added dropwise with vigorous stirring. The product was extracted with ether. The ether layer was washed with sodium bicarbonate solution. Extraction with 10% sodium hydroxide and acidification with 10% HCl gave the product which was extracted with ether, washed with sodium bicarbonate, and dried over anhydrous magnesium sulfate. Solvent was evaporated to give 2.1 g (37%) of the product, mp: 27-29°C (lit. 27-28.5°C),[116]

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.58 (s, 3H), 3.65 (s, 1H), 7.3 (d, J = 8.75 Hz, 2H), 7.8 (d, J = 8.75 Hz, 2H)

4-(3-Buten-1-mercapto)acetophenone:

4-Bromo-1-butene (3.4 g, 0.025 mol) was added to a mixture of 4-mercaptoactophenone (3.75g, 0.025 mol), sodium hydroxide (1.00 g, 0.025 mol) in aqueous ethanol. The mixture was boiled for 2 hours, before being cooled Water was added and mixture extracted with ether. The organic layer was washed with 10% sodium hydroxide solution twice and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford an oil which was purified by column chromatography (20% ethyl acetate/hexanes) then recrystallized from cold acetone to give 3 g of white crystals (mp: 30-31°C).

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.44 (broad, dt, J = 6.93, 6.93 Hz, 2H), 2.56 (s, 3H), 3.05 (t, J = 7.48 Hz, 2H), 5.08 (dq, J = 10.17, 1.58 Hz, 1H), 5.12 (dq, J = 17.03, 1.58 Hz, 1H), 5.86 (ddt, J = 10.31, 17.03, 6.6 Hz, 1H), 7.3 (d, J = 8.76 Hz, 2H), 7.85 (d, J = 8.76 Hz, 2H)

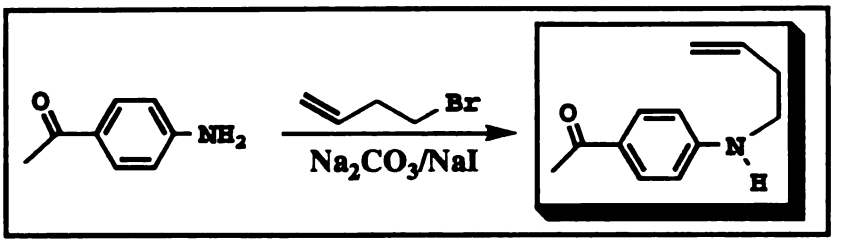
^{13}C NMR ($CDCl_3$) (75 MHz): δ 26.28, 31.16, 32.73, 116.55, 126.32, 128.62, 133.75, 135.71, 144.22, 196.96

IR ($CHCl_3$): 3021, 1677, 1590, 1362, 1265, 1102 cm^{-1}

MS (m/e): 206 (M^+), 191, 165, 137, 129, 123, 108, 91, 77, 69, 55, 43 (base)

Hi-Res MS: $C_{12}H_{14}OS$, Calculated: 206.0766, Found 206.0764

4-(3-Buten-1-amino)acetophenone (p-NH-AP):



4-Bromo-1-butene (1.0g, 0.0074 mol) was added to a mixture of 4-amino-acetophenone (3.0 g, 0.022 mol), anhydrous sodium carbonate (1.0 g, 0.01 mol), and sodium iodide (0.11g, 0.0007 mol) in 40 ml of dry DMF. The mixture was stirred at 80°C for 48 hours under an argon atmosphere, water was then added and the product was extracted with diethyl ether. The organic layer was washed with water four times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford a solid which was purified by flash column (silica gel, 25% ethylacetate/hexanes) to give 0.9 g of the product which was recrystallized from hexanes-ethyl acetate to give 0.81 g (58%) of colorless crystals, mp: 54-55°C.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.39 (tq, J = 1.31, 6.74 Hz, 2H), 2.48 (s, 3H), 3.24 (t, J = 6.77 Hz, 2H), 4.37 (broad, s, 1H), 5.1-5.18 (m, 2H), 5.8 (ddt, J = 10.25, 17.09, 6.81 Hz, 1H), 6.56 (d, J = 8.85 Hz, 2H), 7.81 (d, J = 8.95 Hz, 2H)

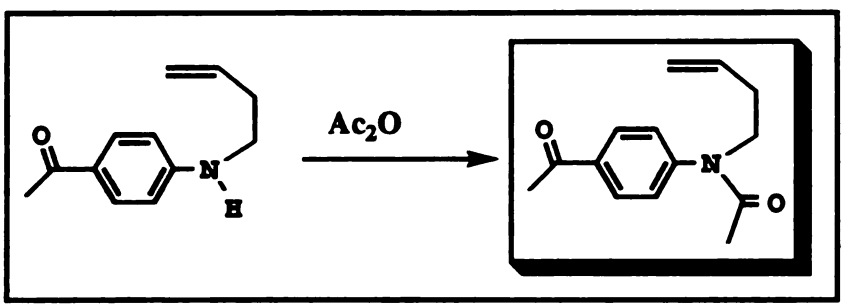
^{13}C NMR ($CDCl_3$) (75 MHz): δ 25.99, 33.33, 42.08, 111.40, 117.54, 126.62, 130.78, 135.1, 152.08, 196.31.

IR ($CHCl_3$): 33428, 3007, 1661, 1601, 1574, 1528, 1482, 1360, 1279, 1181 cm^{-1}

MS (m/e): 189 (M^+), 174, 148 (base), 132, 119, 105, 91, 77, 65, 51, 43

Hi-Res MS: $C_{12}H_{15}NO$, Calculated: 189.1154, Found 189.1161

***N*-Acetyl-4-(3-buten-1-amino)acetophenone (p-NAc-AP):**



4-(3-Buten-1-amino)acetophenone (4.0 g, 0.022 mol) was added to a mixture of acetic anhydride (2.2 ml, 0.022 mol) and acetic acid (2.0 ml, 0.034 mol). The mixture was heated over a steam bath for 1 hour, water (10.0 ml) was added and stirred for 20 minutes After cooling, ether was added and the mixture was washed with 10% sodium hydroxide solution. The ether was dried (magnesium sulfate) and evaporated to give an oil which was vacuum distilled (138-139°C/0.3 mm) to give 3.62 g (74%) of the product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.86 (broad, s, 3H), 2.24 (broad, t, J = 7.17 Hz, 2H), 2.61 (s, 3H), 3.79 (broad, t, J = 7.39 Hz, 2H), 4.99-5.07 (m, 2H), 5.71 (ddt, J = 10.41, 16.94, 6.69 Hz, 1H), 7.27 (d, J = 8.63 Hz, 2H), 8.00 (d, J = 8.51 Hz, 2H)

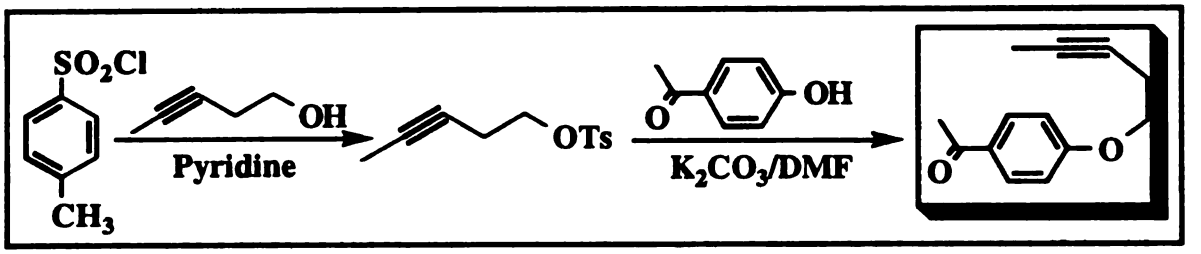
^{13}C NMR ($CDCl_3$) (75 MHz): δ 22.82, 26.63, 32.24, 48.24, 116.94, 128.28, 129.95, 134.93, 136.21, 147.10, 169.70, 196.86.

IR ($CHCl_3$): 3007, 2936, 1688, 1657, 1651, 1601, 1509, 1395, 1360, 1265, 1177, 1144, 959, 922 cm^{-1}

MS (m/e): 231 (M^+), 190, 148 (base), 132, 120, 106, 91, 77, 55, 43

Hi-Res MS: $C_{14}H_{17}NO_2$, Calculated: 231.1259, Found 231.1257

4-(3-Pentyn-1-oxy)acetophenone (p-Ac-TB-Me):



3-Pentynyl-1-tosylate:

3-Pentyne-1-ol (10 g, 0.12 mol) was dissolved in pyridine (16 ml, 0.2 mol). The solution was cooled in an ice bath and *p*-toluenesulfonyl chloride (27.2 g, 0.14 mol) was added in portions. After addition was complete, the mixture was stirred at room temperature overnight. Water was added and the solution was extracted with ether. The ether layer was washed with 10% HCl then with 10% sodium hydroxide solution, dried over magnesium sulfate and evaporated to give 28 g of the crude product which contained some *p*-toluenesulfonyl chloride. Attempts at purification by vacuum distillation led to decomposition of the product. The compound was therefor used without further purification.

4-(3-Pentyn-1-oxy)acetophenone:

3-Pentynyl-1-tosylate (5.4 g, 0.023 mol) was added to a mixture of 4-hydroxyacetophenone (4.0 g, 0.03 mol) and sodium hydroxide (1.18 g, 0.03 mol) in 30 ml of dry DMF. The mixture was stirred at room temperature for one week under an argon atmosphere, water was then added and the product was extracted with diethyl ether. The organic layer was washed with 10% sodium hydroxide solution four times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford 3.5 g of yellowish solid which was purified by vacuum distillation using kugelrohr to give 3.1 g (67.7%) of pure 4-(3-pentyn-1-oxy)acetophenone (mp: 64-65°C).

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.79 (t, *J* = 2.56 Hz, 3H), 2.54 (s, 3H), 2.64 (tq, *J* = 2.59, 7.09 Hz, 2H), 4.09 (t, *J* = 7.15 Hz, 2H), 6.93 (d, *J* = 8.91 Hz, 2H), 7.92 (d, *J* = 8.94 Hz, 2H)

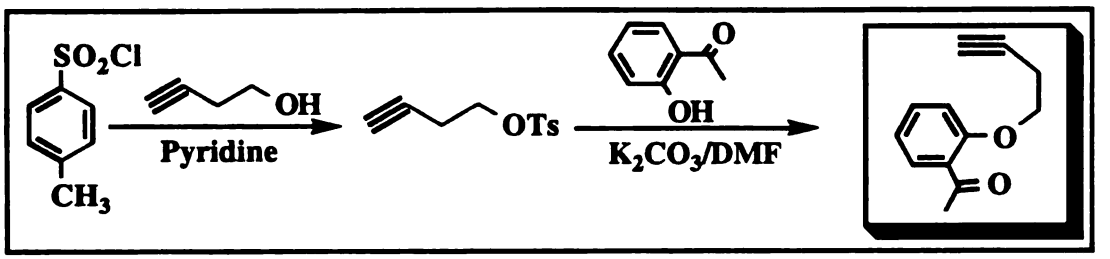
^{13}C NMR ($CDCl_3$) (75 MHz): δ 3.33, 19.51, 26.16, 66.55, 74.46, 77.45, 114.04, 130.29, 130.40, 162.30, 196.54

IR ($CHCl_3$): 3011, 2926, 1674, 1601, 1578, 1510, 1360, 1256, 1173, 1034 cm^{-1}

MS (m/e): 202 (M^+), 187,159, 145, 121, 91, 77, 67 (base), 43, 41

Hi-Res MS: $C_{13}H_{14}O_2$, Calculated: 202.0994, Found 202.0993

2-(3-Butyn-1-oxy)acetophenone (o-Ac-TB-H):



3-Butynyl-1-tosylate:

3-Butyne-1-ol (5.0 g, 0.07 mol) was dissolved in pyridine (36 ml, 0.45 mol). The solution was cooled in ice bath and *p*-toluenesulfonyl chloride (15.5 g, 0.08 mol) was added in portions. After the addition was complete, the mixture was stirred at room temperature overnight. Water was added and the solution was extracted with ether. The ether layer was washed with dilute sulfuric acid then with 10% sodium hydroxide solution, dried over magnesium sulfate and evaporated to give 16 g of the product which was used in the next step without further purification.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.95 (t, J = 2.72 Hz, 1H), 2.43 (s, 3H), 2.53 (dt, J = 2.71, 7.11 Hz, 2H), 4.08 (t, J = 7.11 Hz, 2H), 7.33 (d, J = 8.52 Hz, 2H), 7.79 (d, J = 8.24 Hz, 2H)

2-(3-Butyn-1-oxy)acetophenone:

3-Butynyl-1-tosylate(1.65 g, 0.0074 mol) was added to a mixture of 2-hydroxyacetophenone (1.0 g, 0.0074 mol) and sodium hydride (0.22 g, 0.0092 mol) in 10 ml of dry DMF. The mixture was stirred at room temperature for one week under an argon atmosphere, water was then added and the product was extracted with diethyl ether. The organic layer was washed with 10% sodium

hydroxide solution four times and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford 0.215 g of white solid which was recrystallized from benzene-hexanes to give 0.19 g (14%) of the product, mp: 53-54°C.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.03 (t, *J* = 2.71 Hz, 1H), 2.65 (s, 3H), 2.74 (dt, *J* = 2.72, 6.56 Hz, 2H), 4.18 (t, *J* = 6.58 Hz, 2H), 6.91 (d, *J* = 7.97 Hz, 1H), 7.00 (dt, *J* = 1.01, 7.57 Hz, 1H), 7.43 (ddd, *J* = 1.89, 7.39, 8.52 Hz, 1H), 7.74 (dd, *J* = 1.92, 7.69 Hz, 1H)

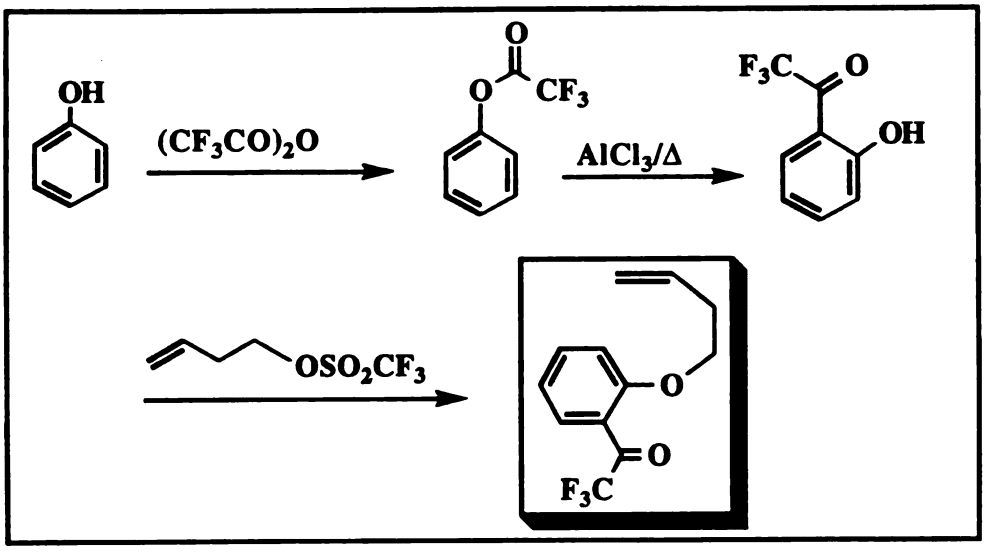
^{13}C NMR ($CDCl_3$) (75 MHz): δ 19.57, 32.19, 66.41, 70.21, 80.28, 112.19, 120.97, 128.4, 130.53, 133.61, 157.7, 199.77

IR ($CHCl_3$): 3310, 3011, 2118, 1673, 1599, 1487, 1453, 1360, 1296, 1246, 1163, 1129, 1045, 1032 cm^{-1}

MS (m/e): 188 (M^+), 173, 149, 145, 131, 121 (base), 115, 105, 91, 77, 65, 53, 43

Hi-Res MS: $C_{12}H_{12}O_2$, Calculated: 188.0837, Found 188.0837

2-(Buten-1-oxy) α,α,α-trifluoroacetophenone(o-BTFAc):



Phenyltrifluoroacetate:

The title compound was prepared according to the procedure of Weggand and Popsch.[117]Trifluoroaceticanhydride (77 ml, 0.5 mol) and phenol (47 g, 0.5 mol) were stirred together. The reaction mixture became hot and started boiling for about 10 minutes, it was then heated at 100°C for 1 hour. The mixture was distilled twice through a fractionation column. The product was collected as the fraction boiling at 144-145°C (literature 149°C-150°C)

2-Hydroxy α,α,α-trifluoroacetophenone:

Following the procedure published by Matsumoto and coworkers.[118] Phenyl trifluoro acetate (10.0 g, 0.053 mol) was added dropwise to a suspension of anhydrous aluminum chloride (8.1 g, 0.061 mol) in carbon disulfide (11 ml). The mixture was stirred at room temperature for one hour, then heated under gentle refluxing for an additional hour. The solvent was distilled off and the reaction temperature was raised gradually to 115°C for 15 minutes then lowered to 90°C

where it was kept for 90 minutes. After cooling the reaction mixture was treated with diluted HCl and steam distilled. The distillate was extracted with ether, washed with water and dried over magnesium sulfate. The organics were filtered and evaporated to give the crude product which was vacuum distilled (118-120/asp) to give 3.8 g (38%) of the product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 6.69 (ddd, *J* = 1.13, 7.2, 8.3 Hz, 1H), 7.07 (dd, *J* = 1.1, 8.61 Hz, 1H), 7.61 (ddd, *J* = 1.63, 7.21, 8.8 Hz, 1H), 7.81 (d of quintets, *J* = 8.39, 2.11 Hz, 1H), 11.05 (s, 1H)

3-Buten-1-triflate:

The title compound was prepared by applying the same method used for preparing 3-butyn-1-triflate.[119] Trifluoromethanesulfonic anhydride (15g, 0.054 mol) and methylene chloride (30 ml) were placed in a 3-neck rb. flask. The solution was stirred under an argon atmosphere, and cooled to -40°C. Finely powdered anhydrous sodium carbonate (3.0 g, 0.028 mol) was added. Then 3-buten-1-ol (3.0 g, 0.042 mol) was added dropwise over a period of 20 minutes while temperature was mentained at -40 to -50°C. Stirring was continued at -30°C for 2 hours, and at 0°C for one hour. The reaction was quenched by the dropwise addition of 10 ml of water. The organic layer was separated and dried over anhydrous magnesium sulfate. After filtration the solvent was removed using rotary evaporator (at room temperature). The product was vacuum distilled (45°C/ asp) to give 5.2 g (61%) of the product.

^{1}H NMR($CDCl_3$) (300 MHz): δ 2.56 (ddq, *J* = 1.4, 1.12, 6.61, 6.61 Hz, 2H), 4.54 (t, *J* = 6.56 Hz, 2H), 5.16~5.28 (m, 2H), 5.74 (ddt, *J* = 17.31, 10.05, 6.7 Hz, 1H)

2-(Buten-1-oxy) α,α,α-trifluoroacetophenone:

The title compound was prepared using a general method published by Beard and coworkers.[120] 3-Buten-1-triflate (5.2 g, 0.025 mol) was added to a mixture of 2-hydroxy-α,α,α-trifluoroacetophenone (4.85 g, 0.025 mol) and anhydrous potassium carbonate (17.0 g, 0.128 mol) in 50 ml of dry methylene chloride. The mixture was stirred at room temperature for 24 hours under an argon atmosphere, water was added and the product was extracted three times with ether. The organic layer was washed with a diluted potassium carbonate solution and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford 4.6 g of oil which was purified by vacuum distillation (128-130/ 0.3 mm) to give 3.2 g (52%) of the pure product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.57 (tq, *J* = 1.31, 6.74 Hz, 2H), 4.09 (t, *J* = 6.68 Hz, 2H), 5.1 (ddt, *J* = 10.23, 1.77, 1.16 Hz, 1H), 5.16 (dq, *J* = 17.18, 1.6 Hz, 1H), 5.88 (ddt, *J* = 10.28, 17.15, 6.78 Hz, 1H), 6.98 (d, *J* = 8.51 Hz, 1H), 7.04 (dt, *J* = 0.91, 7.57 Hz, 1H), 7.55 (ddd, *J* = 1.77, 7.41, 8.45 Hz, 1H), 7.63 (dd, *J* = 1.71, 7.73 Hz, 1H)

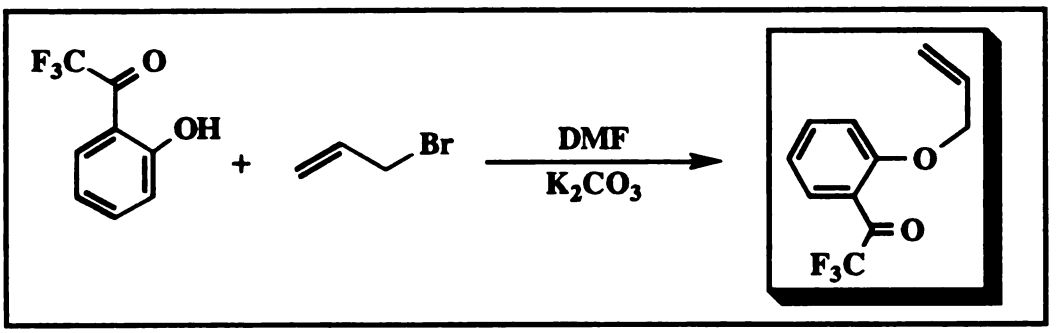
^{13}C NMR ($CDCl_3$) (75 MHz): δ 33.15, 68.24, 112.56, 116.17 (q, *J* = 289 Hz), 117.42, 120.66, 122.04, 131.38, 133.76, 135.71, 158.95, 183.49 (q, *J* = 37 Hz)

IR ($CHCl_3$): 3085, 2942, 1711, 1601, 1489, 1453, 1283, 1252, 1167, 940 cm^{-1}

MS (m/e): 244 (M^+), 203, 188, 175, 153, 121, 95, 92, 65, 55 (base), 39

Hi-Res MS: $C_{12}H_{11}F_3O_2$, Calculated: 244.0711, Found 244.0708

2-(Propen-1-oxy) α,α,α-trifluoroacetophenone (o-PTFAc):



Allyl bromide (7.1 ml, 0.083 mol) was added to a mixture of 2-hydroxy-α,α,α-trifluoroacetophenone (5.0 g, 0.0263 mol) and anhydrous potassium carbonate (3.65 g, 0.0.264 mol) in 50 ml of dry DMF. The mixture was stirred at 65°C for 72 hours under an argon atmosphere. After cooling water was added and the product was extracted with ether. The organic layer was washed with dilute potassium carbonate solution and dried over anhydrous magnesium sulfate. The solvent was evaporated using the rotary evaporator to afford 4.16 g of oil which was purified by vacuum distillation (Kugelrohr) to give 3.36 g (55.2%) of the pure product.

^{1}H NMR ($CDCl_3$) (300 MHz): δ 4.63 (dt, J = 5.25, 1.52 Hz, 2 H), 5.30 (dq, J = 10.59, 1.38 Hz, 1 H), 5.43 (dq, J = 17.28, 1.55 Hz, 1 H), 6.03 (ddt, J = 17.81, 10.56, 5.25 Hz, 1H), 6.99 (d, J = 8.43 Hz, 1 H), 7.03 (dt, J = 0.88, 7.51 Hz, 1 H), 7.54 (ddd, J = 1.8, 7.41, 8.48 Hz, 1 H), 7.65 (dd, J = 7.97, 1.37 Hz, 1 H)

^{13}C NMR ($CDCl_3$) (75 MHz): δ 69.61, 113.13, 116.15 (q, J = 291 Hz), 118.14, 120.76, 121.95, 131.25, 131.95. 135.64, 158.70, 184.26 (q, J = 36.64 Hz)

IR ($CHCl_3$): 3025, 1716, 1606, 1490, 1282, 1185, 1169, 997, 943 cm^{-1}

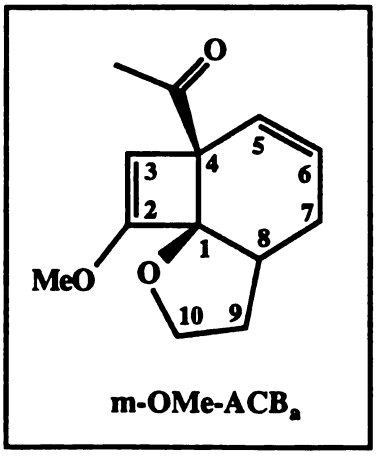
MS (m/e): 231 (MH^+, base), 230 (M^+), 219, 203, 179, 136, 121, 107, 75, 50

Hi-Res MS: $C_{11}H_9F_3O_2$ (observed as MH^+: $C_{11}H_{10}F_3O_2$), Calculated: 231.0633 Found 231.0634

Identification of Photoproducts

Photolysis of m-OMe-pBA:

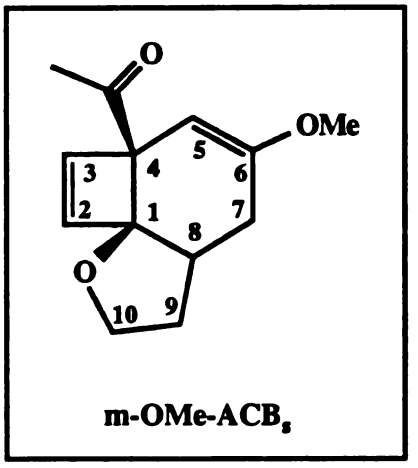
In an NMR tube, 3.1 mg of **m-OMe-pBA** was dissolved in 0.75 ml of benzene-d_6 and purged with argon for 5 minutes. It was irradiated using Pyrex filtered-light ($\lambda \geq 290$ nm). After 45 minutes (30% conversion), ^1H NMR analysis showed the formation of new peaks that corresponds to three products; 4-acetyl-2-methoxy-11-oxa-tricyclo[6.3.0.0^{1,6}]undeca-2,4-diene (**m-OMe-CHD$_a$**), 4-acetyl-2-methoxy-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-OMe-ACB$_a$**) and 4-acetyl-6-methoxy-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-OMe-ACB$_s$**) in a ratio of 1.5 : 4.3 : 1.0 respectively (NMR integration of doublet at 6.08 ppm , doublet of doublets at 6.15 ppm and doublet at 5.96 ppm). After 3.5 hours (100% conversion), only **m-OMe-ACB$_a$** and **m-OMe-ACB$_s$** were present with a ratio of 5.7 : 1.0 respectively (NMR integration of dd at 6.15 ppm and d at 5.96 ppm). They were identified from their partial NMR spectra.



m-OMe-ACB$_a$

4-Acetyl-2-methoxy-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-OMe-ACB$_a$**):

^{1}H NMR (C_6D_6) (300 MHz) (Partial spectrum): δ 2.3 (s, 3H, $COCH_3$), 3.03 (s, 3H, OCH_3), 4.65 (s, 1H, H_3), 5.75 (ddd, J = 1.83, 6.8, 9.95 Hz, 1 H, H_6), 6.15 (dd, J = 2.98, 9.9 Hz, 1H, H_5)



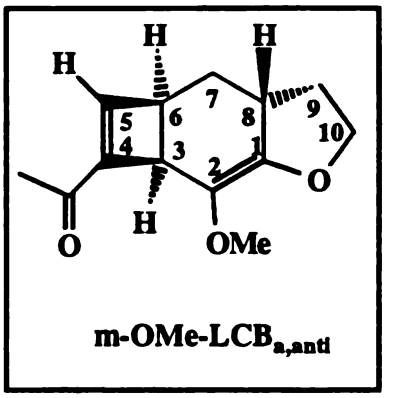
m-OMe-ACB$_s$

4-Acetyl-6-methoxy-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-OMe-ACB$_S$**):

^{1}H NMR (C_6D_6) (300 MHz) (Partial spectrum): δ 2.18 (s, 3H, $COCH_3$), 3.2 (s, 3H, OCH_3), 4.65 (d, overlapped with a peak of the other isomer, H_5), 5.96 (d, J = 2.85 Hz, 1H, H_3), 6.05 (dd, J = 2.85, 0.53 Hz, 1H, H_2),

3.3 mg of the ketone in 0.75 ml of benzene-d6 was irradiated in an NMR tube at 313 nm. After 80 minutes, ^{1}H NMR showed the formation of **m-OMe-CHD$_a$** as the only product. Irradiation was continued for 12 hours. ^{1}H NMR showed the formation of peaks corresponding to **m-OMe-ACB$_a$**, **m-OMe-ACB$_S$**, **m-OMe-CHD$_a$** (5 : 1 : 1) beside singlets at 4.62, 4.94, 5.44, a multiplet at 5.5 and a multiplet at 6.08 ppm. The solution was left at room temperature for 20 hours then

heated at 100°C for 90 minutes. ^{1}H NMR showed that the **m-OMe-CHD$_a$** concentration had increased at the expense of **m-OMe-ACB$_a$**, and the three singlets at 4.62, 4.94 and 5.44 ppm. A new compound was also observed and identified as 4-acetyl-2-methoxy-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-OMe-LCB$_{a,anti}$**).



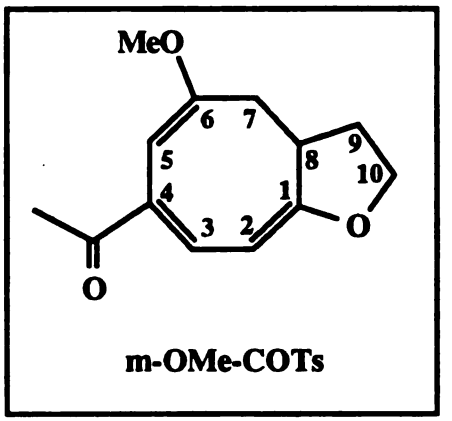
m-OMe-LCB$_{a,anti}$

4-Acetyl-2-methoxy-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (OMe-LCB$_{a,anti}$):

^{1}H NMR (C_6D_6) (300 MHz): δ 0.72 (ddd, J = 13.00, 11.63, 6.1 Hz, 1H, H_7), 1.15 (dddd, J = 11.51, 11.51, 11.05, 8.63 Hz, 1H, H_9), 1.45 (m, 1H, H_9), 1.60 (ddd, J = 13.00, 4.95, 1.65 Hz, 1H, H_7), 1.85 (m, 1H, H_8), 1.95 (s, 3H, CH_3CO) 2.67 (dddd, J = 5.98, 4.43, 1.47, 1.47 Hz, 1H, H_6), 3.48 (ddd, J = 11.75, 8.46, 5.5 Hz, 1H, H_{10}), 3.61 (dd, J = 4.4, 1.25 Hz, 1H, H_3), 3.79 (ddd, J = 8.49, 8.49, 1.1 Hz, 1H, H_{10}), 3.95 (s, 3H, OCH_3), 6.14 (d, J = 1.37 Hz, 1H, H_5)

In an NMR tube 1.7 mg of the ketone was dissolved in 0.75 ml benzene-d_6, degassed and irradiated using uranium-filtered light ($\lambda \geq 334$ nm). After 43 hours of irradiation (> 80% conversion), ^{1}H NMR showed the presence of **m-**

OMe-ACB$_a$ and **m-OMe-ACB$_s$** in a ratio of 2.8 : 1.0 (NMR integration of doublet of doublets at 6.15 and doublet at 5.96 ppm). The solution was left at room temperature in the dark for 5 days. ^{1}H NMR showed the formation of three products; **m-OMe-CHD$_a$** and **m-OMe-COT$_s$** in a ratio of 2.5 : 1.0 (NMR integration of doublet at 6.08 and doublet of doublets at 6.78 ppm) and an unidentified product. **m-OMe-COT$_s$** was identified from its partial NMR spectrum.



m-OMe-COTs

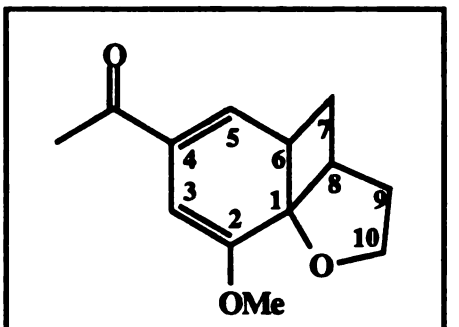
4-Acetyl-6-methoxy-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (m-OMe-COT$_s$):

^{1}H NMR (C_6D_6) (300 MHz) (Partial spectrum): δ 5.54 (dd, *J* = 8.5, 2.4 Hz, 1H, H_2), 5.86 (broad singlet, 1H, H_5), 6.78 (dd, *J* = 8.5, .90 Hz, 1H, H_3)

1.0 g of the ketone in 500 ml dry benzene was irradiated using Pyrex-filtered light (λ ≥ 290 nm) for 12 hours. Solvent was rotary evaporated. ^{1}H NMR of the residue ($CDCl_3$), showed the presence of three compounds; **m-OMe-pBA**, **m-OMe-CHD$_a$** and 4-acetyl-2-methoxy-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-OMe-COT$_a$**) in a ratio of 1.0 : 3.8 : 2.3 (NMR integration of doublet at 6.86, singlet at 5.74 and doublet of triplets at 6.28 ppm). When the sample was left

overnight, ^{1}H NMR showed that **m-OMe-COT$_a$** had totally disappeared while the concentration of **m-OMe-CHD$_a$** increased. **m-OMe-COT$_a$** was identified from its partial NMR spectrum.

The mixture was purified by column chromatography (silica gel, 20% ethyl acetate/hexanes) to give 0.11 g of starting material and 0.37 g of 4-Acetyl-2-methoxy-11-oxa-tricyclo[6.3.0.0^{1,6}]undeca-2,4-diene (**m-OMe-CHD$_a$**).



m-OMe-CHD$_a$

4-Acetyl-2-methoxy-11-oxa-tricyclo [6.3.0.0^{1,6}]undeca-2,4-diene (m-OMe-CHD$_a$):

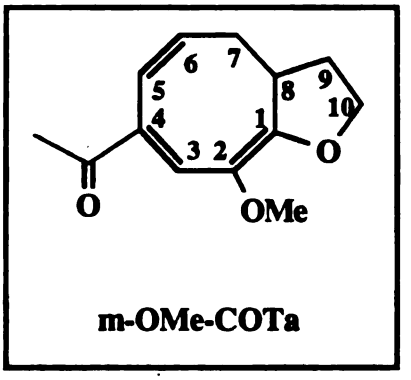
^{1}H NMR ($CDCl_3$) (500 MHz): δ 1.75 (dddd, $J_{9,9}$ = 12.6, $J_{9,10}$ = 6.12, $J_{9,10}$ = 3.7, $J_{8,9}$ = 2.65 Hz, 1 H, H_9), 1.91 (ddd, $J_{7,7}$ = 12.1, $J_{7,6}$ = 10.5, $J_{7,8}$ = 3.8 Hz, 1 H, H_7), 2.05 (dt, $J_{7,7}$ = 12.1, $J_{7,6}$, $J_{7,8}$ = 8.6 Hz, 1 H, H_7), 2.13 (dddd, $J_{9,9}$ = 12.6, $J_{9,10}$ = 9.0, $J_{8,9}$ = 8.7, $J_{9,10}$ = 7.8 Hz, 1 H, H_9), 2.30 (s, 3 H, $COCH_3$), 3.25 (broad t, J = 8.84 Hz, 1 H, H_8), 3.30 (dddd, $J_{6,7}$ = 10.5, $J_{6,7}$ = 8.6, $J_{5,6}$ = 5.85, $J_{6,8}$ = 1.8 Hz, 1 H, H_6), 3.66 (s, 3 H, OCH_3), 4.20 (dt, $J_{9,10}$ = 6.1, $J_{9,10}$, $J_{10,10}$ = 9.0 Hz, 1 H, H_{10}), 4.24 (ddd, $J_{10,10}$ = 9.0, $J_{9,10}$ = 7.8, $J_{9,10}$ = 3.7 Hz, 1 H, H_{10}), 5.75 (d, $J_{3,5}$= 0.83 Hz, 1 H, H_3), 6.44 (dd, $J_{3,5}$= 0.83, $J_{5,6}$ = 5.76 Hz, 1 H, H_5),

^{13}C NMR ($CDCl_3$) (75 MHz): δ 25.22, 28.96, 33.71, 40.79, 48.49, 55.4, 69.24, 81.41, 92.34, 131.77, 134.52, 155.78, 196.95 (C=O)

^{13}C NMR (C_6D_6) (75 MHz): δ 24.95, 28.91, 34.25, 41.36, 48.50, 54.62, 69.66, 92.58, 131.14, 134.98, 157.12, 195.69

UV-Visible (Benzene): λ_{max} = 315 nm, ε = 3515

MS (m/e): 220(M^+), 205, 189, 177, 166, 151, 115, 91, 77, 55 (base)



m-OMe-COTa

4-Acetyl-2-methoxy-11- oxabicyclo[6.3.0]undeca-1,3,5-triene (m-OMe-COT_a):

^{1}H NMR ($CDCl_3$) (300 MHz) (Partial spectrum): δ 2.37 (s, 3H, $COCH_3$), 3.56 (s, 3H, OMe) 5.94 (dt, *J* = 13.13, 5.94 Hz, 1H, H_6), 6.28 (dt, *J* = 13.19, 2.19 Hz, 1H, H_5), 6.98 (br s, 1H, H_3),.

Irradiation of m-OMe-CHD$_a$:

In an NMR tube a solution of 2.8 mg of **m-OMe-CHD$_a$** in 0.8 ml C_6D_6 was purged with argon for 5 minutes then irradiated at 313 nm. After 40 minutes (12% conversion), NMR showed the formation of **m-OMe-pBA**, **m-OMe-ACB$_a$** and another product that has a singlet at 4.9 ppm in a ratio of 2.8 : 1.0 : 6.0 (NMR integration of doublet at 6,48, singlet at 4.65 and singlet at 4.9 ppm, assuming it corresponds to one proton of the unknown product) . This ratio remained the same up to 72% conversion.

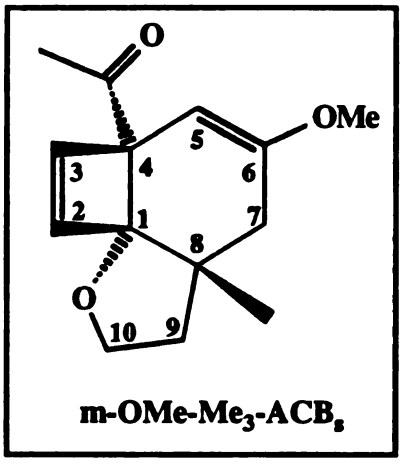
Temperature Effect:

In an NMR tube, a solution of 4.1 mg of **m-OMe-pBA** and 1.9 mg of methylbenzoate in 0.75 ml of benzene-d_6 was purged with argon, placed in ice-water bath and irradiated using Pyrex-filtered light. After 1 hour, ^{1}H NMR showed the presence of starting material (45%), **m-OMe-CHD$_a$** (2.1%), **m-OMe-ACB$_a$** (7.1%)and **m-OMe-ACB$_s$** (1.7%). After 4 hours the percentages became 2.3%, 2.0%, 18.5%, and 4.4%. Ratios were determined using ^{1}H NMR integration with methyl benzoate as an internal standard. The following peaks were chosen for the integration; doublet of doublets at 8.1 ppm for methyl benzoate, singlet at 3.32 ppm for **m-OMe-pBA**, doublet at 5.75 and doublet of doublets at 6.44 for **m-OMe-CHD$_a$**, doublet of doublets at 6.15 for **m-OMe-ACB$_a$** and doublet at 5.96 and doublet of doublets at 6.05 ppm for **m-OMe-ACB$_s$**.

The previous experiment was repeated at 55°C. After 40 minutes, ^{1}H NMR showed the presence of starting material (69.4%), **m-OMe-CHD$_a$** (2.9%), **m-OMe-ACB$_a$** (16.1%), and **m-OMe-ACB$_s$** (4.4%). After 4 hours the percentages became 0.0%, 0.0%, 44%, and 4.6%.

Photolysis of **m-OMe-Me$_3$-pBA**:

0.29 g of **m-OMe-Me$_3$-pBA** in 150 ml of dry benzene was irradiated using Pyrex-filtered light ($\lambda \geq 290$ n.m). The reaction progress was monitored by ^{1}H NMR spectroscopy. After 15 hours irradiation, solvent was removed under vacuum. ^{1}H NMR analysis showed the formation of 4-acetyl-6-methoxy-8-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-OMe-Me$_3$-ACB$_S$**) as the only product. Preparative TLC purification led to the isolation of 0.15 g of the photoproduct as 4-acetyl-6-methoxy-8-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-OMe-Me$_3$-COT$_S$**).



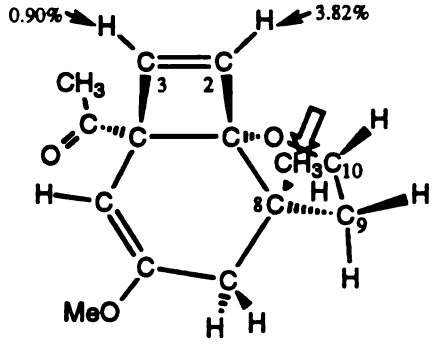
m-OMe-Me$_3$-ACB$_S$

4-Acetyl-6-methoxy-8-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (m-OMe-Me$_3$-ACB$_S$):

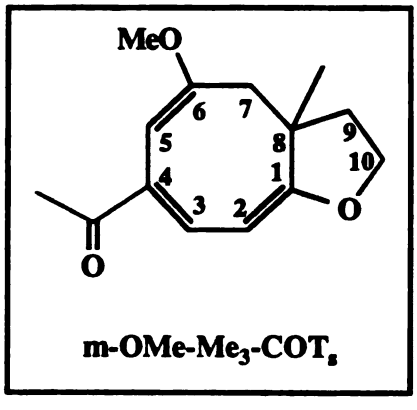
^{1}H NMR (C_6D_6) (500 MHz) (partial spectrum): δ 0.70 (s, 3H, CH_3), 2.13 (s, 3H, CH_3CO) 3.2 (s, 3H, OCH_3), 3.50 (ddd, J = 9.49, 8.17, 7.06 Hz, 1H, H_{10}), 3.59 (ddd, J = 9.72, 8.17, 2.65 Hz, 1H, H_{10}), 4.64 (d, J = 2.0 Hz, 1H, H_5), 6.00 (d, J = 2.93 Hz, 1H, H_3), 6.02 (d, J = 2.93 Hz, 1H, H_2)

nOe NMR Experiment:

(C_6D_6, 500 MHz, 15°C), Irradiation of the singlet at 0.70 ppm led to the enhancement of the doublet at δ 6.00 (3.82 %) and the doublet at δ 6.02 (0.90%).



In an NMR tube, 3.5 mg of **m-OMe-Me$_3$-COT$_S$** 0.75 ml of benzene-d_6 and purged with argon for 5 minutes. It was irradiated using Pyrex filtered-light ($\lambda \geq$ 290 nm). After 60 minutes of irradiation, ^{1}H NMR analysis showed the formation of **m-OMe-Me$_3$-ACB$_S$** with the disappearance of **m-OMe-Me$_3$-COT$_S$**.



m-OMe-Me$_3$-COT$_s$

4-Acetyl-6-methoxy-8-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (m-OMe-Me$_3$-COT$_S$):

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.16 (s, 3H, CH_3), 1.72 (broad, dd, J = 12.15, 5.22 Hz, 1H, H_9), 2.14 (d, J = 14.1 Hz, 1H, H_7), 2.35 (s, 3H, CH_3CO) 2.43 (ddd, J = 11.8, 11.8, 9.34 Hz, 1H, H_9), 2.52 (d, J = 14.1 Hz, 1H, H_7), 3.65 (s, 3H, OCH_3), 4.17 (m, 2H, H_{10}), 5.24 (d, J = 6.16 Hz, 1H, H_2), 5.36 (s, 1H, H_5), 6.98 (d, J = 6.25 Hz, 1H, H_3)

Photolysis of m-SMe-pBA:

In an NMR tube, 1.3 mg of **m-SMe-pBA** was dissolved in 0.75 ml of benzene-d_6 and purged with argon for 5 minutes. It was irradiated using Pyrex filtered light ($\lambda \geq 290$ nm). After 65 minutes of irradiation, ^{1}H NMR analysis showed the formation of new peaks that correspond to three products; 4-acetyl-2-methylmercapto-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-SMe-ACB$_a$**), 4-acetyl-6-methylmercapto-11-oxatricyclo-6.3.0.0^{1,4}]undeca-2,5-diene (**m-SMe-ACB$_S$**) and 4-acetyl-2-mercaptomethyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-SMe-LCB$_{a,anti}$**) in a ratio of 7.5 : 1.2 : 1 (NMR integration of the multiplet at 5.7-5.8 ppm, doublet at 5.86 and doublet at 6.08 ppm).

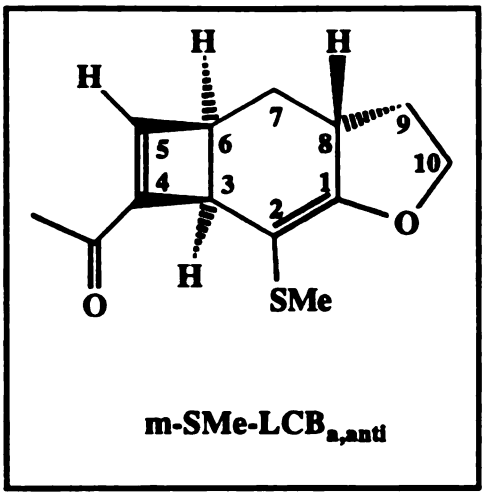
The NMR tube was placed in a boiling water bath for one hour. ^{1}H NMR analysis showed that peaks corresponding to **m-SMe-ACB$_a$** disappeared while increasing the concentration of **m-SMe-LCB$_{a,anti}$**. Peaks corresponding to **m-SMe-ACB$_S$** remained unchanged.

For preparatory scale irradiation, 0.3 g of the ketone in 150 ml dry benzene was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm) for 12 hours under argon atmosphere. ^{1}H NMR of a sample of the reaction mixture ($CDCl_3$), showed the

presence of a small amount of the starting ketone and **m-SMe-ACB$_a$** as the major product in addition to **m-SMe-ACB$_s$** and **m-SMe-LCB$_{a,anti}$** as minor products. Continuing irradiation for three more hours led to the disappearance of **m-SMe-ACB$_a$** without changing the ratio between **m-SMe-ACB$_s$** and **m-SMe-LCB$_{a,anti}$**.

The previous experiment was repeated but irradiation was performed for only 6 hours. A two ml sample was taken from the reaction mixture and the solvent was removed under vacuum. ^{1}H NMR of the residue ($CDCl_3$), again showed the formation of **m-SMe-ACB$_a$** as the major product. When the solution was heated for 25 minutes at 95^{o}C, ^{1}H NMR showed the disappearance of the signals corresponding to **m-SMe-ACB$_a$** with the appearance of new peaks corresponding to **m-SMe-LCB$_{a,anti}$**. Signal integration indicated that this transformation was quantitative.

The remaining of the reaction mixture was placed in the refrigerator for 24 hours. ^{1}H NMR showed the disappearance of peaks corresponding to **m-SMe-ACB$_a$** and the formation of new peaks corresponding to two new compounds; 4-acetyl-2-mercaptomethyl-11-oxa-tricyclo[6.3.0.0^{1,6}]undeca-2,4-diene (**m-SMe-CHD$_a$**) and 4-acetyl-2-mercaptomethyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-SMe-COT$_a$**). Prep TLC (hexanes/ ethylacetate) led to the isolation of **m-SMe-LCB$_{a,anti}$**, 4-acetyl-6-mercaptomethyl-11- oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-SMe-COT$_s$**), and a mixture of **m-SMe-CHD$_a$** and **m-SMe-COT$_a$**. ^{1}H NMR (C_6D_6), of the **m-SMe-CHD$_a$ /m-SMe-COT$_a$** mixture showed that they have a ratio of 2 : 1 (NMR integration of doublet of doublets at 5.96 and doublet of triplets at 5.6 ppm). This ratio remained the same after 24 hours.



m-SMe-LCB$_{a,anti}$

4-Acetyl-2-mercaptomethyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4 diene (m-SMe-LCB$_{a,anti}$):

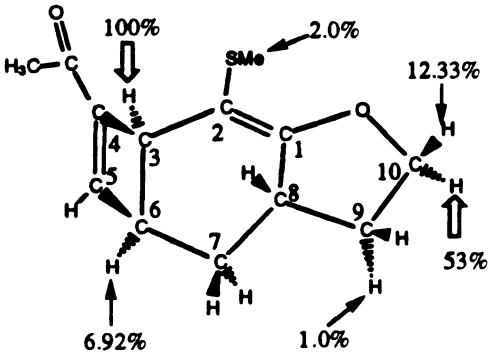
^{1}H NMR (C_6D_6) (500 MHz): δ 0.73 (ddd, *J* = 12.93, 11.76, 5.97 Hz, 1H, H_7), 1.09 (dddd, *J* = 11.82, 11.82, 11.03, 8.53 Hz, 1H, H_9), 1.42 (dddd, *J* = 11.87, 7.82, 5.63, 1.0 Hz, 1H, H_9), 1.6 (ddd, *J* = 12.93, 5.16, 1.6 Hz, 1H, H_7), 1.93 (m, 1H, H_8), 1.97 (s, 3H, $COCH_3$), 2.42 (s, 3H, SCH_3), 2.62 (dddd, *J* = 5.9, 4.4, 1.5, 1.4 Hz, 1H, H_6), 3.44 (ddd, *J* = 11.82, 8.6, 5.62 Hz, 1H, H_{10}), 3.71 (dd, *J* = 4.3, 1.0 Hz, 1H, H_3), 3.75 (ddd, *J* = 8.6, 8.5, 1.0 Hz, 1H, H_{10}), 6.08 (d, *J* = 1.35 Hz, 1H, H_5)

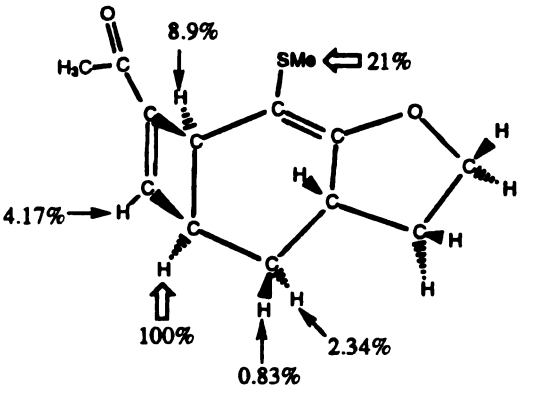
^{1}H NMR ($CDCl_3$) (500 MHz): δ 1.25 (ddd, *J* = 13.03, 11.71, 5.96 Hz, 1H, H_7), 1.75 (dddd, *J* = 11.93, 11.93, 11.27, 8.62 Hz, 1H, H_9), 2.24 (s, 3H, SMe) 2.24 (m, 2H), 2.32 (s,3H, CH_3CO) 2.43 (m, 1H), 3.18 (dddd, *J* = 5.96, 4.41, 1.44, 1.44 Hz, 1H, H_6), 3.75 (dd, 4.42, 1.1 Hz, 1H, H_3), 4.03 (ddd, *J* = 11.93, 8.61, 5.74 Hz, 1H, H_{10}), 4.32 (dd, *J* = 8.6, 8.6 Hz, 1H, H_{10}), 6.8 (d, *J* = 1.35 Hz, 1H, H_5),.

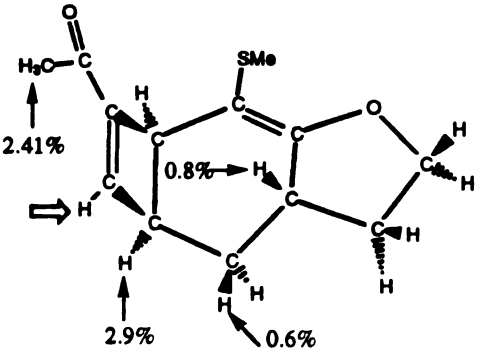
Homonuclear Decoupling NMR Experiment ($CDCl_3$),

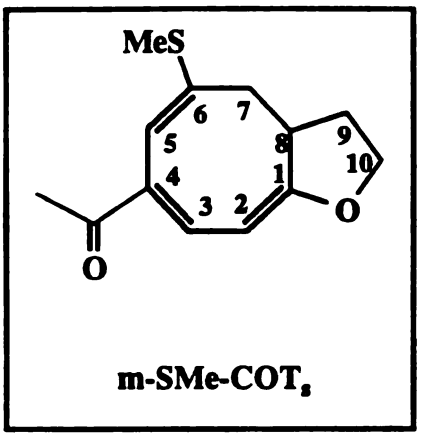
Irradiation of the doublet at 6.8 ppm caused the signal at 3.18 ppm (dddd) to appear as doublet of doublets of doublets (J = 5.96, 4.41, 1.44 Hz).

The stereochemistry of the tricyclo compound was determined using ^1H NMR nOe experiment at 15°C (C_6D_6, 500 MHz). Irradiation of the bridgehead proton at C_3 (3.71 ppm, $H_{10\beta}$ was partially irradiated) induced enhancements of H_6 (6.92%) and the thiomethoxy group (2.0%) Similarly irradiation of H_6 (2.62 ppm, thiomethoxy group was partially irradiated) led to the enhancement of H_3 (8.9%), $H_{7\beta}$ (0.83%) and $H_{7\alpha}$ (2.34%). Irradiation of H_5 led to the enhancement of H_6 (2.9%), $H_{7\beta}$ (0.60%), acetyl group (2.41%) and H_8 (0.8 %).





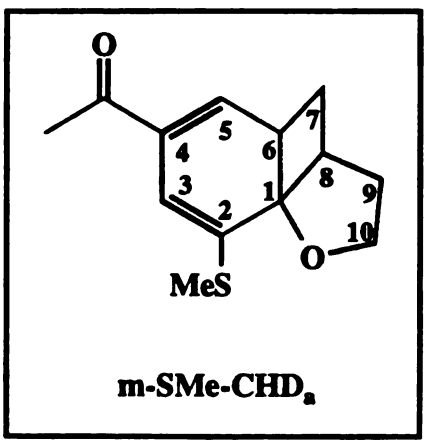




m-SMe-COT$_s$

4-Acetyl-6-mercaptomethyl-11- oxabicyclo[6.3.0]undeca-1,3,5-triene (m-SMe-COT$_S$):

^{1}H NMR ($CDCl_3$) (500 MHz): δ 1.98 (ddt, J = 12.37, 8.39, 11.71 Hz, 1H, H_9), 2.18 (m, 1H, H_9), 2.29 (dd, J = 13.7, 7.95 Hz, 1H, H_7), 2.33 (s, 3H, SMe) 2.36 (s, 3H, CH_3CO) 2.37 (dd, J = 13.92, 2.21 Hz, 1H, H_7), 2.95 (m 1H, H_8), 4.1 (ddd, J = 11.3, 8.61, 5.3 Hz 1H, H_{10}), 4.25 (td, J = 8.5, 1.11 Hz, 1H, H_{10}), 5.5 (dd, J = 9.05, 2.43 Hz, 1H, H_2), 6.06 (s, 1H, H_5), 6.96 (dd, J = 9.05, 0.88 Hz, 1H, H_3)



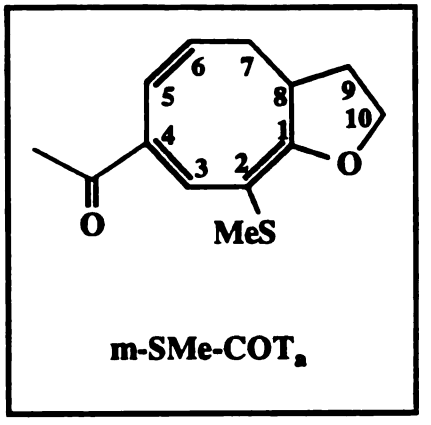
m-SMe-CHD$_a$

4-Acetyl-2-mercaptomethyl-11-oxa-tricyclo[6.3.0.0^{1,6}]undeca-2,4-diene (m-SMe-CHD$_a$):

^{1}H NMR (C_6D_6) (500 MHz): δ 1.15 (ddt, J = 12.37, 5.52, 1.55, Hz, 1H, H_9), 1.40 (ddd, J = 12.25, 10.5, 4.86 Hz, 1H, H_7), 1.69 (ddd, J = 12.25, 9.28, 7.07 Hz, 1H, H_7), 1.80 (m, 1H, H_9), 1.84 (s, 3H, SMe) 1.92 (s, 3H, CH_3CO)2.84 (dddd, J = 10.50, 7.06, 5.75, 1.54 Hz, 1H, H_6), 3.12 (m 1H, H_8), 3.83 (ddd, J = 10.6, 9.15, 5.52 Hz, 1H, H_{10}), 4.08 (ddd, J = 9.15, 7.73, 1.77 Hz, 1H, H_{10}), 5.98 (dd, J = 5.75, 0.70 Hz, 1H, H_5), 6.53 (d, J = 0.70 Hz, 1H, H_3)

Homonuclear Decoupling NMR Experiment:

Irradiation of the signal at 4.08 ppm (ddd) caused the signal at 1.15 (dddd) to appear as a doublet of doublets of doublets and changed the shape of the multiplet at 1.80 ppm. Irradiation of doublet of doublets of doublets at 3.83 ppm caused the signal at 1.15 (dddd) to appear as a doublet of doublets of doublets and changed the shape of the multiplet at 1.80 ppm. Irradiation of the multiplet at 3.12 ppm caused the signal at 1.15 (dddd) to appear as a doublet of doublets of doublets and the doublet of doublets of doublets at 1.4 to appear as a doublet of doublets and the doublet of doublets of doublets at 1.69 to appear as a doublet of doublets. Irradiation of the signal at 2.84 ppm (dddd) caused the doublet of doublets of doublets at 1.40 to appear as a doublet of doublets and the doublet of doublets of doublets at 1.69 to be doublet of doublets and the doublet of doublets at 5.98 to appear as a doublet. Irradiation of the doublet of doublets at 5.98 caused the doublet of doublets of doublets of doublets at 2.84 to appear as a doublet of doublets of doublets and the doublet at 6.53 to appear as a singlet.



m-SMe-COT$_a$

4-Acetyl-2-mercaptomethyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (m-SMe-COT$_a$):

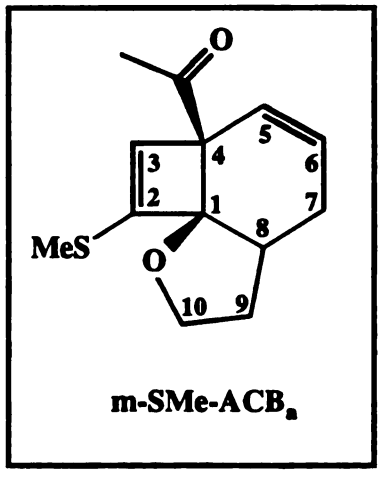
^{1}H NMR (C_6D_6) (500 MHz): δ 0.84 (ddt, J = 12.25, 6.19, 2.55 Hz, 1H, H_9), 1.32 (dddd, J = 12.25, 10.16, 8.62, 7.74 Hz, 1H, H_9), 1.73-1.82 (m, 2H, H_7), 1.97 (s, 3H, SMe) 2.08 (s, 3H, CH_3CO) 2.71 (m, 1H, H_8), 3.64 (ddd, J = 8.84, 8.84, 1.84 Hz, 1H, H_{10}), 3.71 (ddd, J = 10.16, 8.84, 6.18 Hz, 1H, H_{10}), 5.60 (ddd, 13.25, 4.53, 4.53 Hz, 1H, H_6), 6.50 (ddd, J = 13.25, 2.21, 2.21 Hz, 1H, H_5), 7.07 (s, 1H, H_3)

A 3 mg mixture of **m-SMe-CHD$_a$ /m-SMe-COT$_a$** in an NMR tube was dissolved in 0.75 ml of benzene-d_6, purged with argon for 5 minutes and irradiated at room temperature at 313 nm. After 2 hours (65% conversion), ^{1}H NMR analysis showed the formation of **m-SMe-ACB$_a$** (69%), **m-SMe-LCB$_{a,anti}$** (28%) and **m-SMe-pBA** (3%) as shown by integrating; doublet of doublets of doublets at 5.99, doublet at 6.08 and doublet at 6.8 ppm.

A 3 mg mixture of **m-SMe-CHD$_a$ /m-SMe-COT$_a$** in an NMR tube was dissolved in 0.75 ml of benzene-d_6, purged with argon for 5 minutes and irradiated at 365 nm while placed in ice-water bath. After 2 hours irradiation

(~100% conversion), ^{1}H NMR analysis showed the formation of **m-SMe-ACB$_a$** and **m-SMe-LCB$_{a,anti}$** in a ratio of 4.5 : 1. No **m-SMe-pBA** was detected.

Variable temperature NMR of the previous solution at 65°C for 30 minutes, showed that the starting material had totally converted to **m-SMe-LCB$_{a,anti}$**.



m-SMe-ACB$_a$

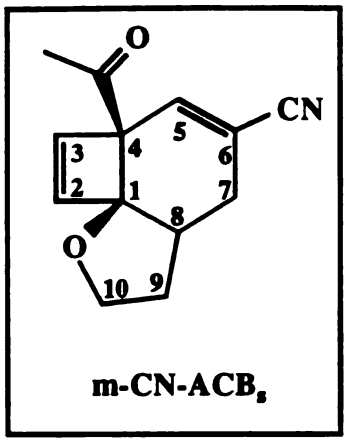
4-Acetyl-2-mercaptomethyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,10-diene (m-SMe-ACB$_a$):

^{1}H NMR (C_6D_6) (500 MHz): δ 1.36 (dddd, *J* = 11.49, 7.07, 5.97, 1.77 Hz, 1H, H_9), 1.65 (m, 1H, H_9), 1.66 (s, 3H, SMe) 1.77 (ddd, *J* = 12.37, 3.3, 5.96 Hz, 1H, H_8), 1.85 (ddd, *J* = 12.37, 2.5, 2.5 Hz, 1H, H_7), 1.9 (m , 1H, H_7), 2.22 (s, 3H, CH_3CO) 3.69 (ddd, *J* = 9.28, 8.4, 7.07 Hz, 1H, H_{10}), 4.08 (ddd, *J* = 9.28, 8.4, 1.98 Hz, 1H, H_{10}), 5.7 (s, 1H, H_3), 5.75 (ddd, *J* = 9.72, 6.63, 1.77 Hz, 1H, H_6), 5.99 (ddd, 9.72, 2.5, 0.60 Hz, 1H, H_5)

Photolysis of m-CN-pBA:

In an NMR tube, 1.9 mg of the ketone was dissolved in 0.75 ml of benzene-d_6 and purged with argon for 5 minutes. It was irradiated using Pyrex filtered light ($\lambda \geq 290$ nm). The starting ketone totally disappeared after 60 minutes. ^{1}H NMR analysis showed the formation of new peaks that corresponds to two products; 4-acetyl-6-cyano-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-CN-LCB$_{S,anti}$**) and 4-acetyl-6-cyano-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-CN-ACB$_S$**) in a ratio of 3.5 : 1.0 respectively (NMR integration of singlet at 5.54 and doublet of doublets at 5.8 ppm). When the solution was left at room temperature for 24 hours, ^{1}H NMR showed the formation of new signals which were attributed to 4-acetyl-6-cyano-11- oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-CN-COT$_S$**).

4.7 mg of the ketone in 1.0 ml of benzene-d6 was irradiated in an NMR tube at 313 nm. After 17 minutes (2% conversion) NMR analysis showed the formation of **m-CN-COT$_S$**. After 1h, 45 minutes NMR showed the formation of **m-CN-COT$_S$**, **m-CN-ACB$_S$**, and **m-CN-LCB$_{S,anti}$** in a ratio of 1 : 1.66 : 20.3 (NMR integration of doublet at 6.68, doublet at 5.38 and singlet at 5.55 ppm). After 3 h the ratio became 1: 2 : 23. After 4h, 30 minutes the ratio became 0 : 1 : 12.



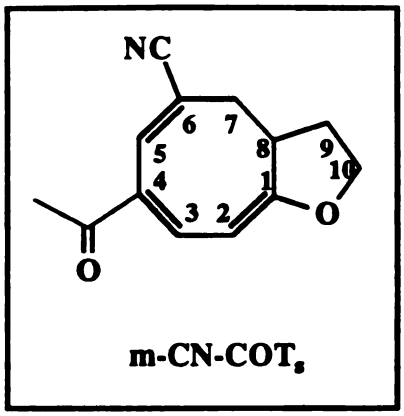
m-CN-ACB$_s$

4-Acetyl-6-cyano-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (m-CN-ACB$_S$):

^{1}H NMR (C_6D_6) (300 MHz) (partial spectrum): δ 1.92 (s, 3H, $COCH_3$),. 3.26 (m, 1H. H_{10}), 3.43 (dt, J = 2.75, 8.58 Hz, 1H, H_{10}), 5.37 (d, J = 2.8 Hz, 1H, H_3), 5.80 (dd, J = 2.8, 0.5 Hz, 1H, H_2), 6.34 (br d, J = 2.8 Hz, 1H, H_5)

A 0.3 g sample of the **m-CN-pBA** in 250 ml dry benzene was irradiated using Pyrex filtered light (λ ≥ 290 nm) for 24 hours. The mixture was purified by column chromatography (silica gel, 20% ethyl acetate/hexanes) to give 0.02 g of starting material, 0.03 g 4-acetyl-6-cyano-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-CN-LCB$_{s,anti}$**) and 0.085 g 4-acetyl-6-cyano-11- oxabicyclo[6.3.0]-undeca-1,3,5-triene (**CN-COT$_S$**).

A 4.1 mg sample of **m-CN-COT$_S$**. in 0.75 ml benzene-d_6 in an NMR tube was irradiated for 25 minutes using Pyrex-filtered light. ^{1}H NMR analysis showed the formation of 4-acetyl-6-cyano-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-CN-LCB$_{s,anti}$**) and 4-acetyl-6-cyano-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-CN-ACB$_S$**) in a ratio of 1.0 : 3.5 respectively (NMR integration of singlet at 5.55 and doublet at 5.38 ppm).



m-CN-COT$_s$

<u>4-Acetyl-6-cyano-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (CN-COT$_S$):</u>

^{1}H NMR (C_6D_6) (500 MHz): δ 1.0 (dddd, J = 12.0, 9.26, 8.59, 7.61 Hz, 1H, H_9), 1.13 (dddd, J = 12.0, 7.3, 6.49, 4.32 Hz, 1H, H_9), 1.82 (ddd, J = 15.0, 8.74, 1.14 Hz, 1H, H_7), 1.84 (s, 3H, $COCH_3$) 1.95 (dd, J = 15.0, 2.98, 1H, H_7), 2.28 (m, 1H, H_8), 3.35 (ddd, J = 8.7, 8.59, 6.49 Hz, 1H, H_{10}), 3.46 (ddd, J = 8.7, 7.61, 4.2 Hz, 1H, H_{10}), 5.28 (dd, J = 8.23, 1.75 Hz, 1H, H_2), 6.69 (d, 8.23 Hz, 1H, H_3), 7.2 (broad, s, 1H, H_5),

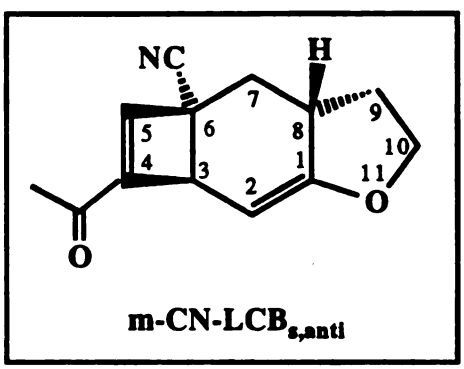
Homonuclear Decoupling NMR Experiment:

Irradiation of the multiplet at 2.28 ppm (dpwr = 20) caused the doublet of doublets at 5.28 to be a doublet (J = 8.23 Hz). Irradiation at 3.4 ppm (dpwr = 25), caused the signal at 1.0 ppm (dddd) to appear as a doublet of doublets (J = 12.0, 9.26 Hz) and the signal at 1.1 ppm (dddd) to appear as a doublet of doublets (J = 12.0, 7.3 Hz). Irradiation of the broad singlet at 7.2 ppm (dpwr = 15), caused the doublet of doublets of doublets at 1.82 to appear as a doublet of doublets (J = 15.0, 8.74 Hz)

^{13}C NMR (C_6D_6) (125 MHz): δ 26.01, 30.96, 32.06, 40.99, 69.20, 96.36, 115.30, 120.66, 130.34, 140.03, 140.73, 172.15, 195.8

UV-Visible (Benzene): λ_{max} = 356 nm, ε = 7110

MS (m/e): 215 (M^+), 200, 172, 154, 144, 130, 117, 103, 89, 77, 55, 43 (base)



m-CN-LCB$_{s,anti}$

rac-(3S,8S,6S)-4-Acetyl-6-cyano-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4 diene (m-CN-LCB$_{s,anti}$)

^{1}H NMR (C_6D_6) (500 MHz): δ 0.87 (dddd, *J* = 12.0, 11.7, 11.11, 8.63 Hz, 1H, H_9), 0.99 (dd, *J* = 13.0, 11.9 Hz, 1H, H_7), 1.23 (ddddd, *J* = 12.0, 7.9, 5.9, 0.90, 0.80 Hz, 1H, H_9), 1.55 (m, 1H, H_8), 1.61 (s, 3H, $COCH_3$), 1.7 (broad dd, *J* = 13.0, 5.2 Hz, 1H, H_7), 3.29 (ddd, *J* = 11.7, 8.6, 5.9 Hz, 1H, H_{10}), 3.59 (d, *J* = 6.5 Hz, 1H, H_3), 3.62 (ddd, *J* = 8.63, 8.6, 0.8 Hz, 1H, H_{10}), 4.99 (dd, *J* = 6.5, 2.5 Hz, 1H, H_2), 5.54 (s, 1H, H_5)

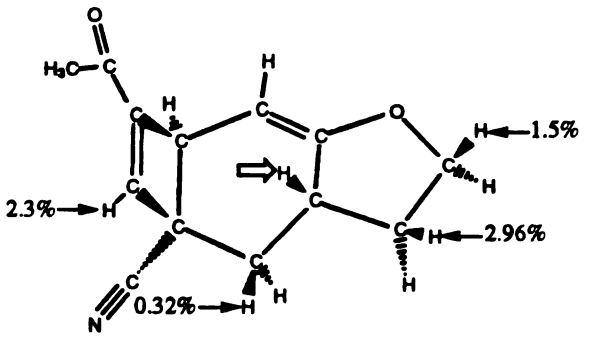
Homonuclear Decoupling NMR Experiment:

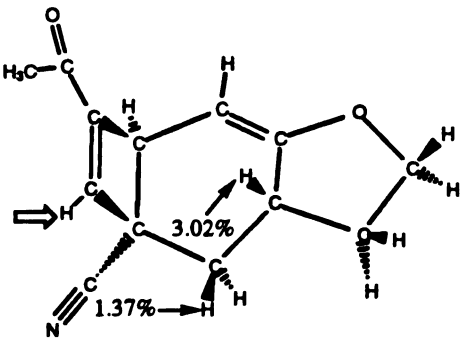
Irradiation of the doublet of doublets of doublets (ddd) at 3.29 ppm (dpwr = 25), caused the signal at 1.23 ppm (ddddd) to appear as a doublet of doublets of doublets of doublets (dddd, *J* = 12.0, 7.9, 0.90, 0.80 Hz). Irradiation at 3.6 ppm

(dpwr = 20) caused the doublet of doublets of doublets of doublets (dddd) at 0.87 to appear as a doublet of doublets of doublets (ddd, J = 12.0, 11.7, 11.11 Hz), and the doublet of doublets (dd) at 4.99 ppm to be a doublet (d, J = 2.5 Hz)

^{1}H NMR ($CDCl_3$) (500 MHz): δ 1.6 (dd, J = 11.80, 13.00 Hz, 1H, H_7), 1.73 (dddd, J = 11.81, 11.63, 10.95, 8.40 Hz, 1H, H_9), 2.21 (s, 3 H, $COCH_3$), 2.23 (m, 1H, H_9), 2.35 (m, 1H, H_8), 2.57 (dd, J = 13.00, 5.01 Hz, 1H, H_7), 3.90 (d, J = 6.6 Hz, 1H, H_3), 3.93 (ddd, J = 11.81, 8.60, 5.52 Hz, 1H, H_{10}), 4.22 (dd, 8.60, 8.40 Hz 1H, H_{10}), 5.0 (dd, J = 6.4, 2.45 Hz, 1H, H_2), 6.63 (s, 1H, H_5)

The stereochemistry of the tricyclo compound was determined by ^{1}H NMR nOe experiment at -10°C ($CDCl_3$, 500 MHz). Irradiation of the bridgehead proton, H_8 (2.35ppm) induced enhancements of $H_{9\beta}$ (2.96%), H_{10} (2.3%), $H_{10\beta}$ (1.5%), and $H_{7\beta}$ (0.32%). Similarly irradiation of H_5 (6.53 ppm) led to the enhancement of H_8 (3.02%) and $H_{7\beta}$ (1.37%). These results suggested that H_8 and the cyclobutene ring are syn to each other.





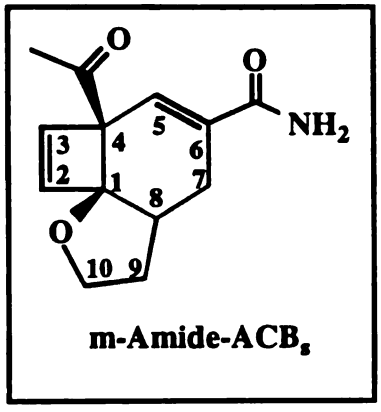
Photolysis of m-Amide-pBA:

In an NMR tube, 1.0 mg of the ketone was dissolved in 0.75 ml of CD3OD and purged with argon for 5 minutes. It was irradiated using Pyrex filtered light (λ ≥ 290 nm). After 15 minutes (~ 50% conversion), the solution was colorless.

Yellow color started to develop a few minutes after stopping the irradiation. NMR analysis showed the formation of new peaks that corresponds to two products; 4-acetyl-6-amido-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Amide-COT$_S$**) and 4-acetyl-6-amido-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-Amide-ACB$_S$**) in a ratio of 1 : 1 (NMR integration of doublet of doublets at 5.5 and doublet at 6.3 ppm). The solution was left overnight in the dark at room temperature, NMR showed that peaks corresponding to **m-Amide-ACB$_S$** had totally disappeared and the concentration of **m-Amide-COT$_S$** was doubled. The solution was irradiated for one more hour (~100% conversion), NMR was taken immediately after irradiation to show that **m-Amide-ACB$_S$** was the major component with trace of **m-Amide-COT$_S$**. After 25 minutes, the **m-Amide-COT$_S$** : **m-Amide-ACB$_S$** ratio was 1.3 : 1.0 and 1.8 : 1.0 after 35 minutes (NMR integration of doublet at 7.3 and doublet at 6.3 ppm). When the solution was left overnight in the dark **m-Amide-ACB$_S$** was totally converted to **m-Amide-COT$_S$**. Irradiation of the **m-Amide-COT$_S$** for one hour converted it back to **m-Amide-ACB$_S$**.

Irradiation of **m-Amide-pBA** was repeated in benzene-d_6. After 80 minutes of irradiation, ^{1}H NMR analysis showed the formation of **m-Amide-ACB$_S$** as the only product. The other regioisomer could not be detected by NMR.

To get a pure sample of **m-Amide-ACB$_S$** for NMR analysis, 2.0 mg of the ketone dissolved in 0.75 ml of CD_3OD in an NMR tube degassed and irradiated for 5 hours. The NMR tube was placed in a dry ice-acetone bath immediately after irradiation. The tube was placed in a precooled NMR probe (-70^{o}C) to slow down rearrangement of the **m-Amide-ACB$_S$** to **m-Amide-COT$_S$**.



m-Amide-ACB$_5$

4-Acetyl-6-amido-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (m-Amide-ACB$_5$):

^{1}H NMR (CD$_3$OD) (500 MHz, -70°C) δ 1.77 (ddt, J = 9.9, 9.0 , 11.93 Hz, 1H, H_9), 1.89 (ddt, J = 12.0, 2.57, 6.9 Hz, 1H, H_9), 2.21 (s, 3H, CH_3CO) 2.24 (ddd, J = 17.0, 5.7, 3.0 Hz, 1H, H_7), 2.45 (m, 1H, H_8), 2.71 (dd, J = 17.0, 3.0 Hz, 1H, H_7), 3.71 (ddd, J = 8.7, 8.2, 2.54 Hz, 1H, H_{10}), 3.78 (ddd, J = 9.9, 8.2, 6.9 Hz, 1H, H_{10}), 6.31 (d, J = 2.78 Hz, 1H, H_3), 6.48 (dd, J = 2.78, 0.6 Hz, 1H, H_2), 6.58 (broad, d, J = 2.88 Hz, 1H, H_5)

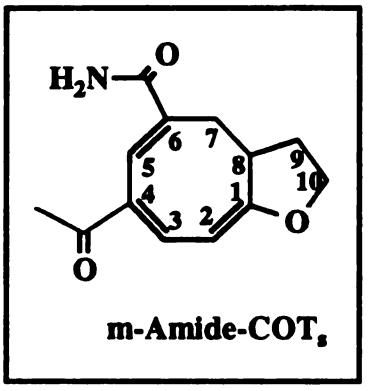
Homonuclear Decoupling NMR Experiment:

Irradiation of proton at 6.48 ppm (dpwr = 10), caused the doublet at 6.31 to appear as a singlet. Irradiation of the doublet at 6.58 ppm caused the signal at 2.24 ppm (ddd) to appear as a doublet of doublets (dd, J = 17.0, 5.7 Hz) and the doublet of doublets (dd) at 6.48 to be a doublet (d, J = 2.78 Hz). Irradiation at 3.8 ppm (dpwr = 25), caused the doublet of doublets of triplets (ddt) at 1.77 to be a triplet (t, J = 11.93 Hz) and the doublet of doublets of triplets (ddt) at 1.89 to be doublet of doublets (dd, J = 12.0, 6.9 Hz)

^{1}H NMR (C_6D_6) (300 MHz): δ 2.1 (s, 3H, CH_3CO) 2.81 (ddd, J = 17.1, 2.8 Hz, 1H), 3.38 (ddd, J = 9.56, 8.15, 6.69 Hz, 1H, H_{10}), 3.53 (dt, J = 2.69, 9.04 Hz, 1H, H_{10}), 5.6 (d, J = 2.8 Hz, 1H, H_3), 5.97 (dd, J = 2.8, 0.6 Hz, 1H, H_2), 6.23 (d, J = 2.8 Hz, 1H, H_5)

^{13}C NMR (CD_3OD) (125 MHz, -70°C): δ 24.15, 28.02, 30.12, 40.76, 67.97, 68.08, 92.37, 132.51, 132.89, 139.35, 140.99, 173.31, 212.84

A 1.0 g sample of the ketone in 500 ml dry methanol was irradiated using Pyrex filter (λ ≥ 290 nm) for 24 hours. The mixture was purified by column chromatography (silica gel, 40% ethyl acetate/hexanes) to give 0.3 g of 4-acetyl-6-amido-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Amide-COT$_S$**).



m-Amide-COT$_s$

4-Acetyl-6-amido-11- oxabicyclo[6.3.0]undeca-1,3,5-triene (m-Amide-COT$_S$):

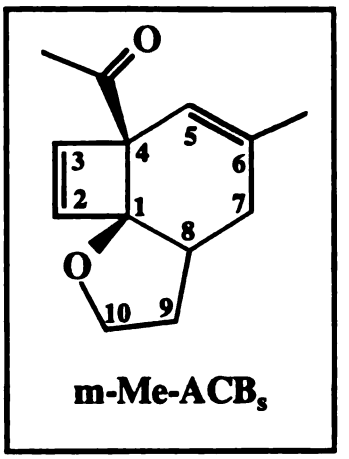
^{1}H NMR (CD_3OD) (300 MHz): δ 1.89 (ddt, J = 8.0, 10.40, 11.58, 1H, H_9), 2.25 (m, 1H, H_9), 2.37 (s, 3H, CH_3CO) 2.44 (dd, J = 13.8, 7.9 Hz, 1H, H_7), 2.89 (dd, J = 13.8, 2.8 Hz, 1H, H_7), 3.05 (m, 1H, H_8), 4.16 (ddd, J = 10.1, 8.3, 5.7 Hz, 1H, H_{10}), 4.25 (ddd, J = 8.3, 8.3, 2.5 Hz, 1H, H_{10}), 5.49 (dd, J = 8.5 , 2.0 Hz, 1H, H_2), 7.16 (s, 1H, H_5), 7.30 (d, J = 8.5 Hz, 1H, H_3)

^{13}C NMR (CD_3OD) (125 MHz, -40°C): δ 26.49, 29.23, 33.1, 44.31, 70.71, 97.05, 131.58, 132.36, 138.70, 142.05, 173.5, 175.38, 201.54

UV-Visible (Methanol): λ_{max} = 353 nm, ε = 4707

Photolysis of **m-Me-pBA**:

In an NMR tube 1.3 mg of **m-Me-pBA** was dissolved in 0.75 ml of benzene-d_6 and purged with argon for 5 minutes. It was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). The reaction course was monitored by ^{1}H NMR. After 2 hours of irradiation (70% conversion), 4-acetyl-6-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-Me-ACB$_S$**) was the only product detected by ^{1}H NMR (12% yield, measured by using the solvent peak as an internal standard). After 5 hours another product was detected, and was characterized as a **di-π–methane** product of **m-Me-ACB$_S$** in a ratio of 1.0 : 2.17 (NMR integration of doublet of doublets at 5.13 and doublet at 5.9 ppm). This ratio became 1.0 : 1.0 after four more hours of irradiation, and their formation yield with respect to consumed starting material was 20% (combined).



m-Me-ACB$_s$

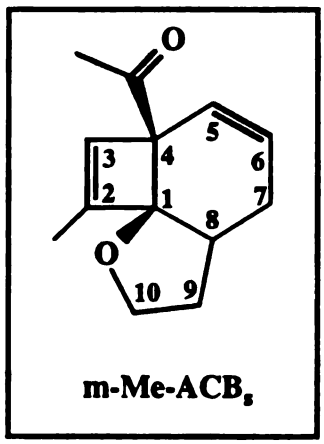
4-Acetyl-6-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undec-2,5-diene (**m-Me-ACB$_s$**):

^{1}H NMR (C_6H_6) (500 MHz): δ 1.33 (ddt, J = 11.8, 2.9, 6.7 Hz, 1H, H_9), 1.57 (broad singlet, 3H, CH_3), 1.68-1.75 (m, 2H), 1.85- 1.91 (m, 2H), 2.13 (s, 3H, $COCH_3$), 3.52 (ddd, J = 9.27, 8.02, 6.99 Hz, 1H, H_{10}), 3.67 (ddd, J = 8.8, 8.28, 2.88 Hz, 1H, H_{10}), 5.5 (broad singlet, 1H, H_5), 5.91 (d, J = 2.88 Hz, 1H, H_3), 6.07 (dd, J = 2.8, 0.50 Hz, 1H, H_2),

In an NMR tube, 2.4 mg of **m-Me-pBA** in 0.75 ml benzene-d_6 was degassed and irradiated using uranium glass filtered light (λ ≥ 334 nm). The tube was taped to the immersion well (this caused the solution temperature to be slightly higher than room temperature). The reaction was followed by ^{1}H NMR. After 105 hours of irradiation (85% conversion), ^{1}H NMR showed the formation of **m-Me-ACB$_s$** and 4-acetyl-2-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-Me-ACB$_a$**) in a ratio of 6.3 : 1.0 and with a chemical yield of 72% and 11.5% respectively (with respect to consumed **m-Me-pBA**). Irradiation was continued until **m-Me-pBA** disappeared. The ratio became 8.0 : 1.0 and the chemical yield was 60% and 7.5%. The experiment was repeated with placing the

NMR tube about one inch away from the immersion well. NMR showed the formation of only **m-Me-ACB$_S$**.

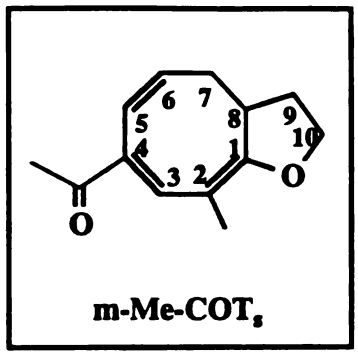
The solution was left at room temperature in the dark for two weeks. ^{1}H NMR showed that both (**m-Me-ACB$_S$**) and (**m-Me-ACB$_a$**) remained unchanged. A catalytic amount of *p*-toluenesulfonic acid was added to the solution and shaken. Yellow color was developed in a few seconds. ^{1}H NMR showed that **m-Me-ACB$_S$** and **m-Me-ACB$_a$** had disappeared with the formation of 4-acetyl-6-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**Me-COT$_t$**) and 4-acetyl-2-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**Me-COT$_a$**).



m-Me-ACB$_s$

4-Acetyl-2-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undec-2,5-diene (m-Me-ACB$_a$):

^{1}H NMR (C_6H_6) (300 MHz) (partial spectrum): δ 1.48 (d, *J* = 1.60 Hz, 3H, CH_3), 5.57 (ddd, *J* = 9.8, 6.2, 3.5 Hz, 1H, H_6), 5.64 (q, *J* = 1.6 Hz, 1H, H_3), 5.92 (ddd, *J* = 10.0, 2.5, 1.3 Hz, 1H, H_5)



m-Me-COT$_s$

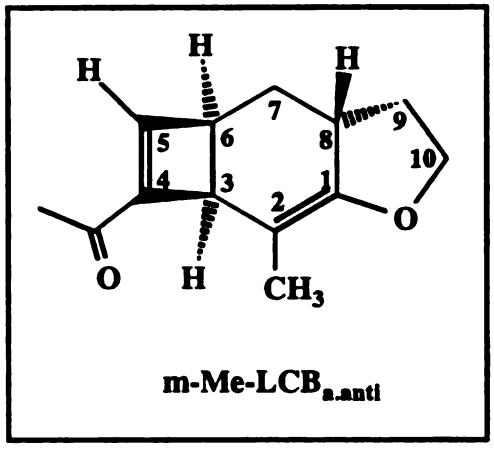
4-Acetyl-2-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene(m-Me-COT$_a$):

^{1}H NMR (C_6H_6) (300 MHz) (partial spectrum): δ 5.65 (dt, J = 12.6, 4.39 Hz, 1H, H_6), 6.58 (dt, J = 12.6, 2.32 Hz, 1H, H_5), 6.83 (s, 1H, H_3),

In an NMR tube 2.4 mg of **m-Me-pBA** dissolved in 0.75 ml benzene-d_6 was degassed and irradiated for 7 hours at 55°C using uranium filtered light ($\lambda \geq$ 334 nm). ^{1}H NMR analysis showed the formation of 4-acetyl-2-methyl-11-oxatricyclo [6.3.0.0^{3,6}]undeca-1,4 diene (**m-Me-LCB$_{a,anti}$**) and **m-Me-ACB$_t$** in a ratio of 4.0 : 1.0 (NMR integration of doublet at 6.04 and doublet at 5.92 ppm). Irradiation was continued for 48 more hours (90% conversion). The ratio became 1.0 : 1.7 while chemical yields were 3.6% and 6.2% respectively (with respect to **m-Me-pBA** consumed).

Similarly, 3.4 mg of **m-Me-pBA** in 0.75 ml benzene-d_6 was irradiated at 365 nm (during irradiation the solution became warm from the lamp). After 24 hours irradiation (~ 33% conversion), ^{1}H NMR showed the formation of **m-Me-LCB$_{a,anti}$** and **m-Me-ACB$_s$** in a ratio of 2.0 : 1.0 (NMR integration of doublet at 6.08 and s at 5.91 ppm) and chemical yields of 67% and 33% with respect to **m-Me-pBA** consumed. After 100 hours irradiation, the ratio became 1 : 1.2 while chemical yield went down to 11% and 9%.

The previous experiment was repeated. ^{1}H NMR showed the formation of three products; **m-Me-ACB$_S$, m-Me-ACB$_a$, and m-Me-LCB$_{a,anti}$** with a ratio of 2.1 : 3.3 : 1 (NMR integration of doublet at 6.08, doublet at 5.95, and doublet at 6.08 ppm). At the end of irradiation the ratio became 3.5 : 5.5 : 1.



m-Me-LCB$_{a,anti}$

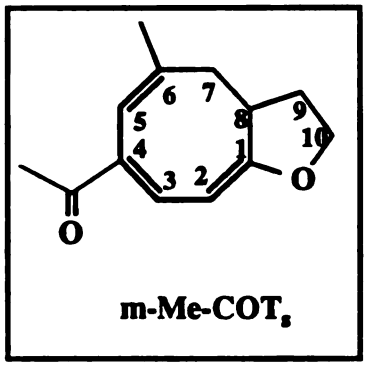
4-Acetyl-2-methyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (m-Me-LCB$_{a,anti}$):

^{1}H NMR (C_6H_6) (300 MHz): δ 0.86 (ddd, *J* = 12.80, 11.60, 6.0 Hz, 1H, H_7), 1.21 (dddd, *J* = 11.57, 11.57, 11.41, 8.39 Hz, 1H, H_9), 1.55 (dddd, *J* = 11.56, 7.41, 5.43. 0.95 Hz, 1H, H_9), 1.78 (ddd, *J* = 12.9, 5.2, 2.0 Hz, 1H, H_7), 1.92 (m, 1H, H_8), 2.27 (d, *J* = 2.27 Hz, 3H, CH_3), 2.66 (ddt, *J* = 5.97, 4.2, 1.4 Hz, 1H, H_6), 3.38 (dd, *J* = 4.10, 0.75 Hz, 1H, H_3), 3.52 (m, 1H, H_{10}), 3.81 (dt, *J* =.55, 8.24 Hz 1H, H_{10}), 6.03 (d, *J* = 1.3 Hz, 1H, H_5)

Homonuclear Decoupling NMR Experiment:

Irradiation of proton at 6.03 ppm caused doublet of doublets of triplets (ddt) at 2.66 to appear as a doublet of doublets of doublets (ddd, *J* = 5.97, 4.2, 1.4 Hz)

A 1.0 g sample of **m-Me-pBA** in 500 ml dry benzene was irradiated using Pyrex filtered light ($\lambda \geq 290$ nm) for 24 hours. The mixture was purified by column chromatography (silica gel, 10% ethyl acetate/hexanes) to give 0.1 g of 4-acetyl-6-methyl-11- oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Me-COT$_S$**).

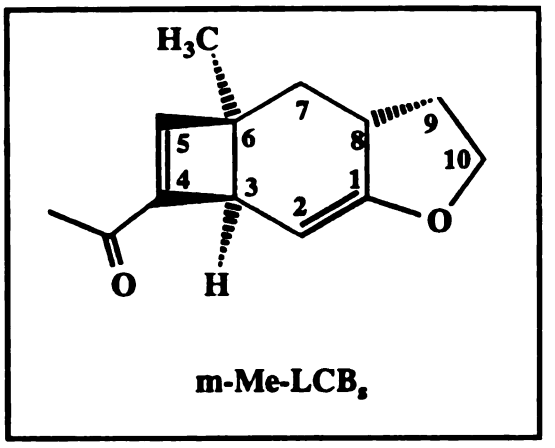


m-Me-COT$_s$

4-Acetyl-6-methyl-11- oxabicyclo[6.3.0]undeca-1,3,5-triene (m-Me-COT$_S$):

^{1}H NMR (C_6H_6) (300 MHz): δ 1.11 (dddd, J = 11.6, 9.0, 8.7, 7.9 Hz, 1H, H_9), 1.28 (ddt, J = 11.5, 4.10, 6.6 Hz, 1H, H_9), 1.6 (d, J = 1.46 Hz, 3H, CH_3), 1.78 (dd, J = 14.07, 2.54 Hz, 1H, H_7), 1.99 (ddd, J = 14.05, 9.58, 0.90 Hz, 1H, H_7), 2.08 (s, 3H, $COCH_3$), 2.41 (m, 1H, H_8), 3.51 (dt, J = 6.32, 8.64 Hz, 1H, H_{10}), 3.64 (ddd, J = 8.6, 7.7, 4.0 Hz, 1H, H_{10}), 5.58 (dd, J = 8.20, 1.90 Hz, 1H, H_2), 6.54 (broad singlet, 1H, H_5), 6.84 (d, J = 8.20 Hz, 1H, H_3),.

In an NMR tube 2.0 mg of **m-Me-COT$_S$** was dissolved in benzene-d_6, degassed and irradiated at 365 nm for four hours. ^{1}H NMR showed the formation of **m-Me-ACB$_S$** and **m-Me-LCB$_{a,anti}$** in a ratio of 3.6 : 1.0



m-Me-LCB$_s$

4-Acetyl-6-methyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4diene (**m-Me-LCB$_{s,anti}$**):

^{1}H NMR (C_6H_6) (300 MHz) (partial spectrum): δ 0.99 (s, 3H, CH_3) 1.86 (s, 3H, $COCH_3$), 3.05 (broad d, J = 6.32 Hz, 1H, H_3), 3.49 (ddd, J = 11.8, 8.67, 5.55 Hz, 1H, H_{10}), 3.8 (dt, J = 0.80, 8.80 Hz, 1H, H_{10}), 5.32 (dd, J = 6.35, 2.5 Hz, 1H, H_2), 6.14 (s, 1H, H_5),

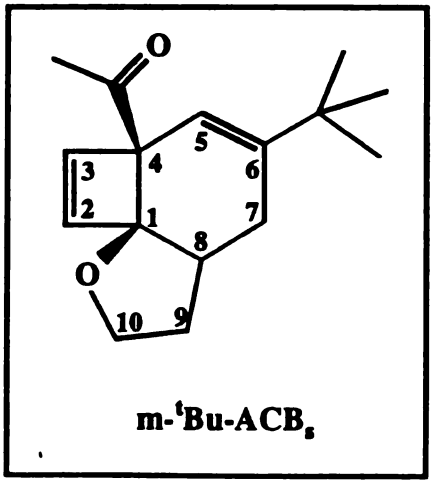
Temperature Effect:

In an NMR tube, a solution of 3.8 mg of **m-Me-pBA** and 2.2 mg of methylbenzoate in 0.75 ml of benzene-d_6 was purged with argon, placed in ice-water bath and irradiated using Pyrex-filtered light. After 1 hour, ^{1}H NMR showed the presence of starting material (84.8%) and **m-Me-ACB$_S$** (5.4%). After four hours the percentages became 55.2% and 13.1% where as after 9 hours they became 35.5% and 17.1% respectively. Ratios were determined using ^{1}H NMR integration and methyl benzoate as the internal standard. The following peaks were chosen for the integration; doublet of doublets at 8.1 ppm for methyl benzoate, the multiplet at 5.01-5.16 ppm for **m-Me-pBA** and doublet at 5.91 ppm for **m-Me-ACB$_S$**.

The previous experiment was repeated at 55°C. After 40 minutes, ^{1}H NMR showed the presence of starting material (65%), **m-MeACB$_S$** (7.3%) and **m-Me-LCB$_{a,anti}$** (14.2%). After 4 hours the percentages became 27.5%, 10.0% and 13.6% respectively. Doublet at 6.03 ppm was chosen for NMR integration for **m-Me-LCB$_{a,anti}$**.

Photolysis of m-^{t}Bu-pBA:

In an NMR tube, 1.3 mg of **m-^{t}Bu-pBA** was dissolved in 0.75 ml of benzene-d_6 and purged with argon for 5 minutes. It was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm) at room temperature. The reaction course was monitored by ^{1}H NMR. After 40 minutes of irradiation , 4-acetyl-6-*t*-butyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-^{t}Bu-ACB$_S$**) was the only product detected by ^{1}H NMR. After 20 hours irradiation, starting material totally disappeared and **m-^{t}Bu-ACB$_S$** was the only product detected by ^{1}H NMR analysis.

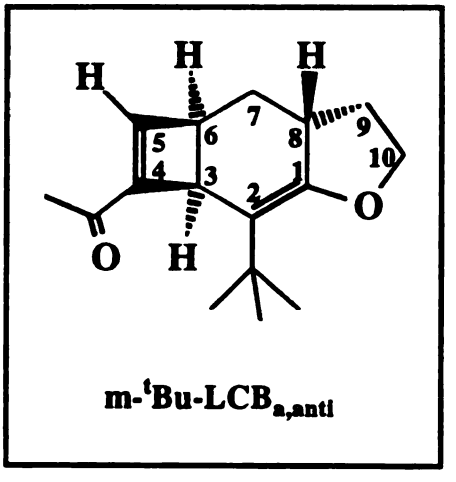


m-^{t}Bu-ACB$_s$

4-Acetyl-6-*t*-butyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (m-^{t}Bu-ACB$_{s}$):

^{1}H NMR (C_6H_6) (500 MHz) (partial spectrum): δ 0.95 (s, 9 H, *t*-Bu) 2.15 (s, 3H, CH_3CO) 3.56 (ddd, J = 9.28, 8.17, 7.07 Hz, 1H, H_{10}), 3.68 (ddd, J = 8.83, 7.95, 2.87 Hz, 1H, H_{10}), 5.68(broad d, J = 2.35 Hz, H_5), 5.88 (d, J = 2.85 Hz, H_3), 6.10 (dd, J = 2.75, 0.55 Hz, H_2),

A 0.5 g sample of **m-^{t}Bu-pBA** in 150 ml of dry benzene was irradiated using Pyrex filtered light (λ ≥ 290 nm). The solution became warm during irradiation. After 12 hours, solvent was evaporated and ^{1}H NMR showed the formation of a new product. Preparative TLC purification (5% ethyl acetate-hexanes) led to the isolation of 0.05 g of unreacted starting material and 0.15 g of the new product which was identified as 4-acetyl-2-*t*-butyl-11-oxatricyclo [6.3.0.0^{3,6}]undeca-1,4-diene (**m-^{t}Bu-LCB$_{a,anti}$**).



m-^{t}Bu-LCB$_{a,anti}$

4-Acetyl-2-*t*-butyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (m-^{t}Bu-LCB$_{a,anti}$):

^{1}H NMR (C_6H_6) (500 MHz): δ 0.85 (ddd, J = 12.4, 11.93, 6.19 Hz, 1H, H_7), 1.18 (tdd, J = 11.7, 11.05, 8.62 Hz, 1H, H_9), 1.53 (dddd, J = 11.71, 7.74, 5.53, 1.1 Hz, 1H, H_9), 1.67 (s, 9 H, *t*-Bu) 1.74 (ddd, J = 12.50, 4.86, 1.55 Hz, 1H, H_7), 1.81 (s, 3H, CH_3CO) 2.02 (tdd, broad, J = 11.5, 7.3, 4.1 Hz, 1H, H_8), 2.67 (ddt, J = 5.96, 4.3, 1.55 Hz, 1H, H_6), 3.47 (ddd, J = 11.71, 8.62, 5.74 Hz, 1H, H_{10}), 3.77 (td, J = 8.17, 1.11 Hz, 1H, H_{10}), 3.82 (dd, J = 4.2, 0.88 Hz, 1H, H_3), 5.97 (d, J = 1.3 Hz, 1H, H_5)

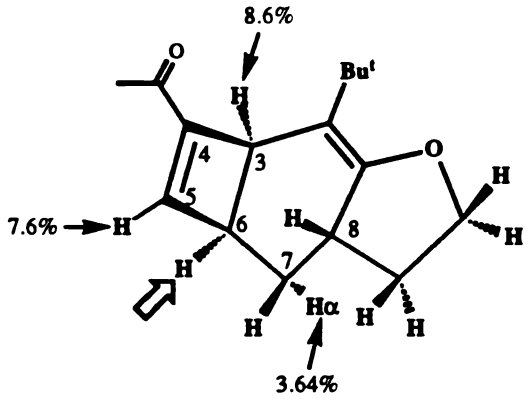
Homonuclear Decoupling NMR Experiment (C_6D_6, 300 MHz):

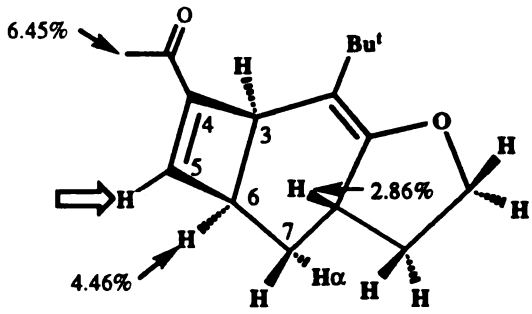
Irradiation of proton at 2.67 ppm caused doublet at 5.97 ppm to appear as a singlet, doublet of doublets at 3.88 ppm to appear as a doublet (J = 0.88 Hz), doublet of doublets of doublets (ddd) at 0.85 to appear as a doublet of doublets (J = 12.3, 12.3 Hz) and doublet of doublets of doublets (ddd) at 1.74 to be doublet of doublets (dd, J = 12.5, 4.8 Hz)

^{13}C NMR (C_6D_6) (75 MHz): δ 25.16, 29.90, 31.45, 31.83, 34.04, 34.47, 40.69, 41.74, 68.40, 111.21, 144.77, 148.57, 154.02, 192.63

MS (m/e): 246(M^+), 231, 203, 189, 177, 163, 147, 119, 105, 91, 77, 55 , 43(base)

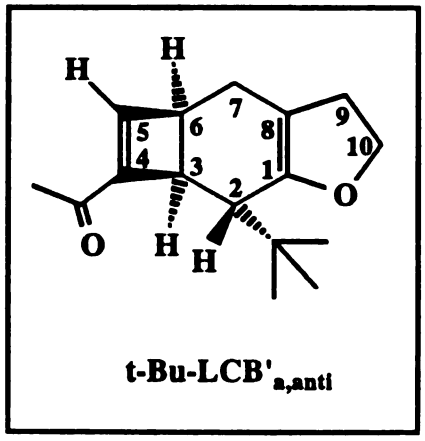
The stereochemistry of **m-^{t}Bu-LCB$_{a,anti}$** was determined using ^{1}H NMR nOe experiment at 25°C (benzene-d_6, 500 MHz). Irradiation of the bridgehead proton, H_6 (2.67 ppm) induced enhancements of H_5 (7.6%), H_3 (8.6%) and $H_7\alpha$(3.64%). Similarly, irradiation of H_5 lead to the enhancement of H_6 (4.46%), H_8 (2.86%) and CH_3CO (6.45%). These results suggested that H_8 and the cyclobutene ring are syn to each other.





A sample of **m-^{t}Bu-LCB$_{a,anti}$** in benzene-d_6 was treated with a catalytic amount of *p*-toluenesulfonic acid. ^{1}H NMR showed the formation of a new compound in equilibrium with **m-^{t}Bu-LCB$_{a,anti}$** in a ratio of 1 : 1.16 (NMR integration of doublet at 5.97 and doublet at 5.94 ppm). When **m-^{t}Bu-LCB$_{a,anti}$** was dissolved in $CDCl_3$ (which has acidic impurities) the same mixture was observed by ^{1}H NMR. This mixture was separated by preparative TLC (5% ethylacetate/ hexanes) and the new product was identified as 4-acetyl-2-*t*-butyl-11-oxatricyclo [6.3.0.0^{3,6}]undeca-1$_8$,4 diene (**m-^{t}Bu-LCB'$_{a,anti}$**).

m-^{t}Bu-LCB'$_{a,anti}$ in benzene-d_6 was treated with a crystal of *p*-toluenesulfonic acid. ^{1}H NMR showed the formation of the same 1 : 1 mixture of **m-^{t}Bu-LCB$_{a,anti}$** and **m-^{t}Bu-LCB'$_{a,anti}$**.



t-Bu-LCB'$_{a,anti}$

4-Acetyl-2-*t*-butyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1$_8$,4-diene(m-^{t}Bu-LCB'$_{a,anti}$)

^{1}H NMR (C_6D_6) (500 MHz): δ 1.03 (s, 9 H, *t*-Bu) 1.72 (s, 3 H, CH_3CO) 1.87 (broad d, J = 16.57 Hz, 1H, H_7), 2.25 (m, 3H), 2.69 (dd, J = 7.6, 4.2 Hz, 1H, H_6), 2.88 (broad s, 1H, H_2), 3.31 (d, J = 4.2 Hz, 1H, H_3), 3.94 (ddd, J = 10.39, 9.05, 9.05 Hz, 1H, H_{10}), 4.03 (ddd, J = 10.16, 8.84, 7.2 Hz, 1H, H_{10}), 5.94 (d, J = 1.33 Hz, 1H, H_5),

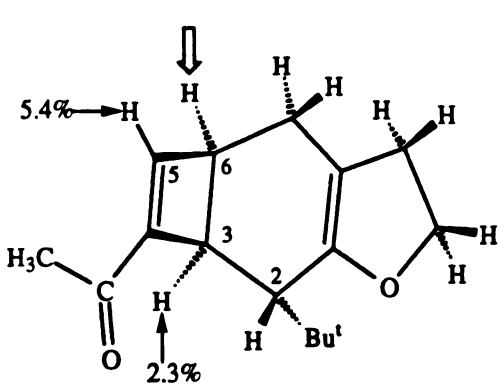
Homonuclear Decoupling NMR Experiment (C_6D_6) (500 MHz).

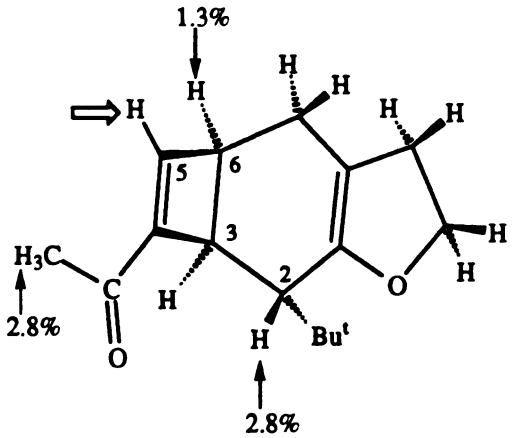
Irradiation of protons at 2.24 ppm caused doublet of doublets of doublets (ddd) at 4.03 ppm to appear as a doublet (J = 9.05 Hz), doublet of doublets (ddd) at 3.94 ppm to appear as a doublet (J = 9.05 Hz), doublet of doublets (dd) at 2.69 ppm to appear as a doublet (J = 4.0 Hz) and doublet at 1.87 to appear as a singlet. Irradiation of proton at 3.31 ppm caused doublet of doublets (dd) at 2.69 ppm to be a doublet (J = 7.7 Hz).

^{13}C NMR (C_6D_6) (75 MHz): δ 24.86, 28.47, 33.93, 36.65, 39 11, 42.51, 44.87, 68.00, 101.84, 145.11, 148.21, 153.1, 192.4

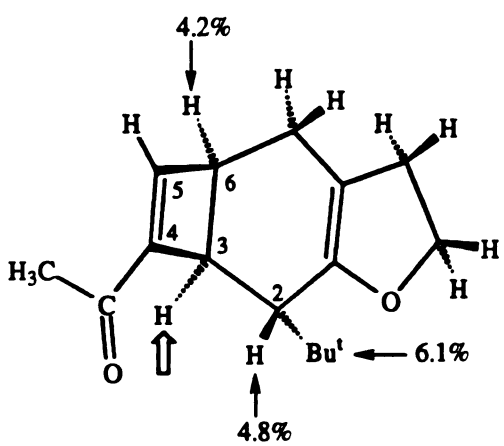
MS (m/e): 246 (M^+), 231, 189, 175, 147, 120, 91, 84, 57 , 43 (base)

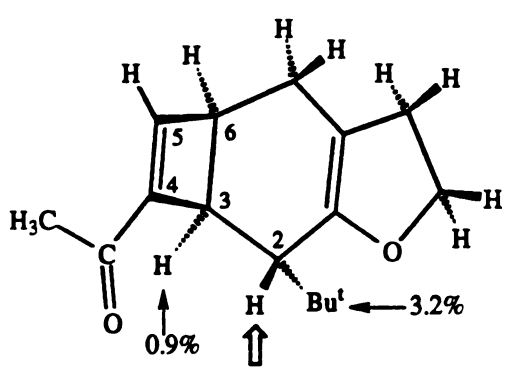
The stereochemistry of **m-^{t}Bu-LCB'$_{a,anti}$** was determined using ^{1}H NMR nOe experiment at 35°C (benzene-d_6, 500 MHz). Irradiation of H_6 (2.69 ppm) induced enhancements of H_5 (5.4%) and H_3 (2.3%). Irradiation of H_5 lead to the enhancement of H_6 (1.3%), H_2 (2.8%), and the methyl group (2.8%).





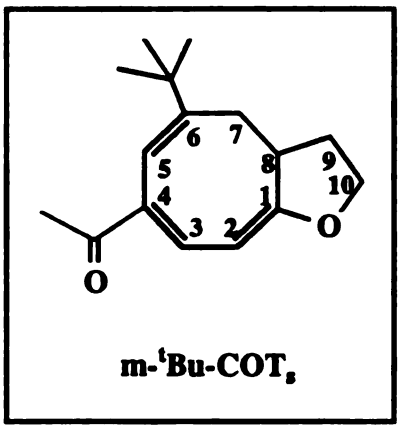
Similarly, irradiation of H_3 caused enhancement of H_6 (4.2%), H_2 (4.8%), and the *t*-butyl group (6.1%), while irradiation of H_2 lead to the enhancement of H_3 (0.9%) and the *t*-butyl group (3.2%).





A 0.3 g sample of **m-^{t}Bu-pBA** in 150 ml of dry methanol was placed in a container surrounding the emmersion well and purged with argon during irradiation. The reaction container was surrounded with ice-water bath to prevent heating of the reaction mixture, then it was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). After 6 hours, solvent was removed under vacuum. ^{1}H NMR analysis showed the formation of **m-^{t}Bu-ACB$_S$**. No **m-^{t}Bu-LCB$_{a,anti}$** was detected. The

photoproduct was isolated using preparative TLC (10% ethylacetate/hexane) as 4-acetyl-6-*t*-butyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-^{t}Bu-COT$_s$**).



m-^{t}Bu-COT$_s$

4-Acetyl-6-*t*-butyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (m-^{t}Bu-COT$_s$):

^{1}H NMR (C_6H_6) (500 MHz): δ 1.08 (s, 9H, *t*-Bu) 1.13 (dddd, *J* = 11.71, 11.71,10.83, 8.18 Hz, 1H, H_9), 1.37 (m, 1H, H_9), 2.05 (s, 3H, CH_3CO) 2.2 (broad, d, *J* = 13.48 Hz, 1H, H_7), 2.27 (ddd, *J* = 13.38, 8.62, 0.85 Hz, 1H, H_7), 2.47 (m, 1H, H_8), 3.43 (ddd, *J* = 10.6, 8.52, 5.52 Hz, 1H, H_{10}), 3.58 (ddd, *J* = 8.4, 8.4, 1.77 Hz, 1H, H_{10}), 5.55 (dd, *J* = 9.28, 2.3 Hz, 1H, H_2), 6.75 (s, broad, 1H, H_5), 6.82 (d, *J* = 9.28 Hz, 1H, H_3)

Homonuclear Decoupling NMR Experiment (C_6D_6, 500 MHz):

Irradiation of the broad singlet at 6.75 ppm caused the broad doublet at 2.20 ppm to appear as a sharp doublet of doublets (dd, *J* = 13.48, 1.74 Hz).

Temperature Effect:

In an NMR tube, a solution of 4.7 mg of **m-^{t}Bu-pBA** and 2.6 mg of methylbenzoate in 0.75 ml of benzene-d_6 was purged with argon, placed in ice-water bath, and irradiated using Pyrex-filtered light. After 1 hour, ^{1}H NMR showed the presence of starting material (94.6%) and **m-^{t}Bu-ACB$_S$** (4.9%). After 4 hours the percentages became 66.0% and 14.6% where as after 9 hours they became 30% and 19.1% respectively. The NMR tube was placed in boiling water for 40 minutes. ^{1}H NMR showed that **m-^{t}Bu-ACB$_S$** remained unchanged. Ratios were determined using ^{1}H NMR integration and methyl benzoate as internal standard. The following peaks were chosen for the integration; doublet of doublets (dd) at 8.1 ppm for methyl benzoate, the multiplet at 5.15-5.2 ppm for **m-^{t}Bu-pBA** and doublet at 5.88 ppm for **m-^{t}Bu-ACB$_S$**.

The previous experiment was repeated at 55°C. After 40 minutes, ^{1}H NMR showed the presence of starting material (62.4%), **m-^{t}Bu-ACB$_S$** (2.2%), and **m-^{t}Bu-LCB$_{a,anti}$** (20.1%). After 4 hours the percentages became 18.9%, 3.4% and 27.9% respectively. The doublet at 5.97 ppm was chosen for NMR integration for **m-^{t}Bu-LCB$_{a,anti}$**.

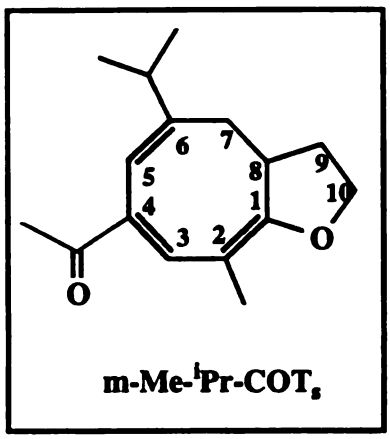
Photolysis of m-Me-iPr-pBA:

In an NMR tube, 1.8 mg of **m-Me-iPr-pBA** was dissolved in 0.75 ml of methanol-d4 and purged with argon gas for 5 minutes. It was irradiated at room temperature using uranium glass-filtered light ($\lambda \geq 334$ nm). The reaction was followed by ^{1}H NMR. The starting material had totally disappeared after about 200 hours of irradiation. ^{1}H NMR Showed the formation of 4-acetyl-6-isopropyl-2-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-Me-iPr-ACB$_S$**) as the

major product (65% with respect to all products formed). The olefinic proton region showed only signals corresponding to **m-Me-iPr-ACB$_S$** and trace amount of its corresponding cyclooctatriene; 4-acetyl-6-isopropyl-2-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Me-iPr-COT$_S$**). The solution was left at room temperature in the dark for 3 days. ^{1}H NMR analysis showed the formation of 1 : 1 mixture of the two compounds.

A 0.15 g sample of **m-Me-iPr-pBA** was dissolved in 150 ml dry methanol. The solution was placed in a container surrounding the emmersion well and purged with argon during irradiation. The reaction container was surrounded with an ice-salt bath to prevent heating of the reaction mixture, then it was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). After 2.5 hours, solvent was removed using rotary evaporator. ^{1}H NMR analysis of the crude product showed the formation of **m-Me-iPr-ACB$_S$**. Attempts to isolate a pure sample of this product were not successful (preparative TLC, hexane/ethylacetate), the isolated product (0.027 g) had some impurities which could not be separated from the product.

A 0.4 g sample of **m-Me-iPr-pBA** was irradiated the same way as the previous experiment. After the solvent was removed, ^{1}H NMR showed the formation of **m-Me-iPr-ACB$_S$**. The crude product was dissolved in ethylacetate and a crystal of *p*-toluenesulfonic acid was added to the mixture. The color turned yellow immediately. Preparatory TLC (5% ethylacetate/hexane) gave 0.61 g (15%) of the product. ^{1}H NMR showed that the product was **m-Me-iPr-COT$_S$**.

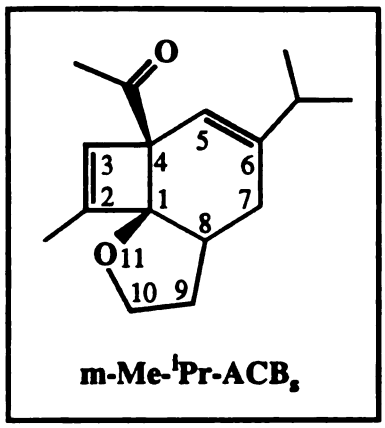


m-Me-^{i}Pr-COT$_s$

4-Acetyl-6-isopropyl-2-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (m-Me-iPr-COT$_S$):

^{1}H NMR (CD_3OD) (300 MHz): δ 1.07 (d, J = 6.08 Hz, 3H, CH_3 of ^{i}pr), 1.08 (d, J = 6.8 Hz, 3H, CH_3 of ^{i}pr), 1.75 (broad s, 3H, 2-Me), 1.82 (dddd, J = 12.3, 6.2, 2.8, 2.8 Hz, 1H, H_9), 2.15 (dddd, J = 12.3, 10.0, 8.6, 7.5 Hz, 1H, H_9), 2.30 (broad sept, J = 6.8 Hz, 1H, ^{i}pr methine), 2.34 (m, 2H, H_7), 2.35 (s, 3 H, CH_3CO), 3.09 (m, 1H, H_8), 4.24 (ddd, J = 8.64, 8.64, 2.88 Hz, 1H, H_{10}), 4.39 (ddd, J = 9.87, 8.64, 6.17 Hz, 1H, H_{10}), 6.06 (broad s, 1H, H_5), 7.04 (broad s, 1H, H_3)

A 6.6 mg sample of **m-Me-iPr-COT$_S$** was dissolved in 0.75 ml of methanol-d4 and purged with argon gas for 5 minutes. The solution was irradiated using Pyrex-filtered light (λ ≥ 290 nm). After 40 minutes, ^{1}H NMR showed the formation of **m-Me-iPr-ACB$_S$** as the only product. The solution was placed in boiling water bath for one hour. ^{1}H NMR showed that the compound remained unchanged even after standing at room temperature for four days (note that the methanol-d_4 used in this experiment was different from the one used before).



m-Me-^{i}Pr-ACB$_s$

4-Acetyl-6-isopropyl-2-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (m-Me-^{i}Pr-ACB$_S$)

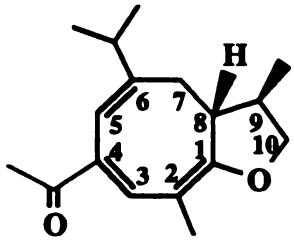
^{1}H NMR (CD$_3$OD) (300 MHz): δ 1.02 (d, *J* = 6.8 Hz, 3H, CH$_3$ of ^{i}pr), 1.04 (d, *J* = 6.8 Hz, 3H, CH$_3$ of ^{i}pr), 1.72 (d, *J* = 1.59 Hz, 3H, 2-Me), 1.89 (m, 2H, H$_9$), 2.10 (s, 3H, CH$_3$CO), 2.11 (ddd, *J* = 16.4, 5.6, 2.0 Hz, 1H, H$_7$), 2.19 (dd, *J* = 16.5, 4.3 Hz, 1H, H$_7$), 2.27 (broad sept, *J* = 6.8 Hz, 1H, ^{i}pr methine), 2.35 (m, 1H, H$_8$), 3.79 (dd, *J* = 8.4, 4.0 Hz, 1H, H$_{10}$), 3.80 (dd, *J* = 8.4, 6.7 Hz, 1H, H$_{10}$), 5.42 (dd, *J* = 2.0, 1.1 Hz, 1H, H$_5$), 5.9 (d, *J* = 1.57 Hz, 1H, H$_3$)

^{1}H NMR (C$_6$D$_6$) (300 MHz) (partial spectrum): δ 0.945 (d, *J* = 6.86 Hz, 3H, CH$_3$ of ^{i}pr) 0.949 (d, *J* = 6.86 Hz, 3H, CH$_3$ of ^{i}pr), 1.53 (d, *J* = 1.53 Hz, 3H, 2-Me) 2.14 (s, 3H, CH$_3$CO), 2.53 (m, 1H, H$_8$), 3.57 (ddd, *J* = 8.67, 8.67, 7.21 Hz, 1H, H$_{10}$), 3.71 (ddd, *J* = 8.6, 8.6, 3.3 Hz, 1H, H$_{10}$), 5.64 (broad s, 1H, H$_5$), 5.68 (q, *J* = 1.51 Hz, 1H, H$_3$)

Photolysis of m-Me-^{i}Pr-Me$_2$-pBA:

In an NMR tube, 1.5 mg of **m-Me-^{i}Pr-Me$_2$-pBA** was dissolved in 0.75 ml of methanol-d4 and purged with argon gas for 5 minutes. It was irradiated at room temperature using Pyrex-filtered light ($\lambda \geq 334$ nm). ^{1}H NMR Showed the formation of 4-acetyl-6-isopropyl-2-methyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-Me-^{i}Pr-Me$_2$-ACB$_S$**) as the major product and another isomer in a ratio of 9 : 1 (NMR integration of doublet at 1.74 and doublet at 1.64 ppm).

A 0.08 g sample of **m-Me-^{i}Pr-Me$_2$-pBA** was dissolved in 150 ml of dry methanol. The solution was placed in a container surrounding the emmersion well and purged with argon during irradiation. The reaction container was surrounded with an ice-salt bath to prevent heating of the reaction mixture, then it was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). After 2.0 hours, solvent was removed using rotary evaporator. ^{1}H NMR analysis of the crude product showed the formation of **m-Me-^{i}Pr-Me$_2$-ACB$_S$**. The oil was dissolved in 1 ml of ethyl acetate and treated with a catalytic amount of *p*-toluenesulfonic acid. The color turned yellow immediately. The product was isolated using preparatory TLC (5% ethylacetate/hexane). ^{1}H NMR showed the isolated product to be **m-Me-^{i}Pr-Me$_2$-COT$_S$** (0.10 g, 12%).



m-Me-^{i}Pr-Me$_2$-COT$_S$

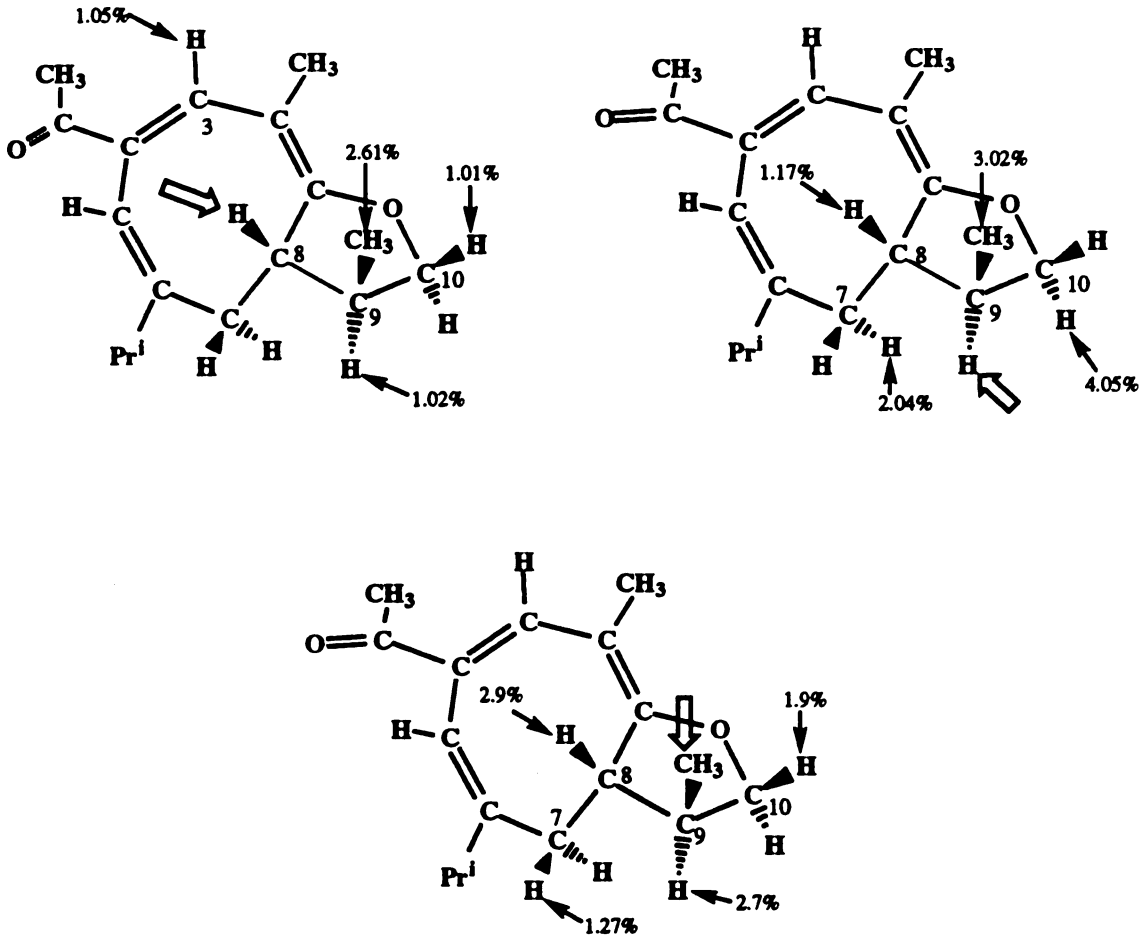
4-Acetyl-6-isopropyl-2,9-dimethyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (m-Me-^{i}Pr-Me$_2$-COT$_S$):

^{1}H NMR (CD_3OD) (300 MHz): δ 0.99 (d, J = 6.87 Hz, 3H, 9-Me), 1.15 (d, J = 6.86 Hz, 6H, isopropyl), 1.76 (broad singlet, 3H, 2-Me), 2.12 (m, 1H, H_9), 2.23 (ddd, J = 16.8, 10.11, 1.22 Hz, 1H, H_7), 2.27 (broad septet, J = 6.6 Hz, 1H, ^{i}pr methine), 2.35 (s, 3H, CH_3CO), 2.41 (ddd, J = 16.3, 3.69, 1.34 Hz, 1H, H_7), 2.66 (m, 1H, H_8), 3.78 (dd, J = 8.75 Hz, 1H, H_{10}), 4.46 (dd, J = 8.75, 6.0 Hz, 1H, H_{10}), 6.06 (broad, s, 1H, H_5), 7.05 (s, 1H, H_3)

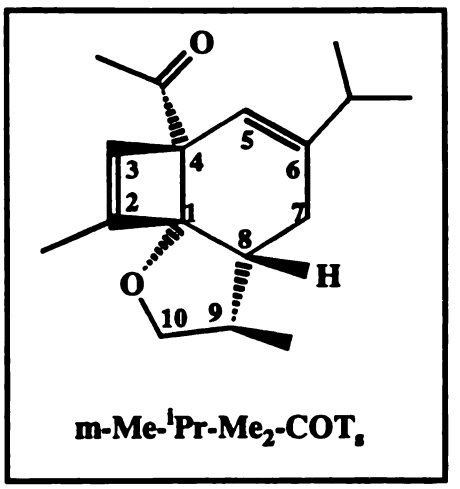
Homonuclear Decoupling NMR Experiment:

Irradiation of methyl group at 0.99 ppm simplified the pattern of the multiplet at 2.12 ppm. Irradiation of the olefinic proton at 6.06 ppm caused the doublet of doublets of doublets (ddd) at 2.41 ppm to appear as a doublet of doublets (dd, J = 16.3, 3.84 Hz) and the doublet of doublets of doublets (ddd)at 2.23 ppm to appear as a doublet of doublets (dd, J = 16.3, 10 Hz) and the broad septet at 2.27 to appear sharp. Irradiation of the methyl group at 1.76 ppm simplified the multiplet at 2.66 ppm to appear as a doublet of doublet of doublets (ddd, J = 10.2, 4.15, 3.55 Hz)

The stereochemistry of **m-Me-^{i}Pr-Me$_2$-COT$_S$** was determined using ^{1}H NMR nOe experiment at 25°C (methanol-d4, 500 MHz). Irradiation of the bridgehead proton H_8 lead to the enhancement of the methyl group at C_9 (2.61%), H_3 (1.06%), H_9 (1.02%) and $H_{10\beta}$ (1.02%). Irradiation of H_9 caused the enhancement of H_8 (1.17%), $H_{10\alpha}$ (4.05%), $H_{7\alpha}$ (2.04%) and the methyl group attached to C_9 (3.02%). Irradiation of the methyl group attached to C_9 lead to the enhancement of H_8 (2.9%), $H_{10\beta}$ (1.9%), H_9 (2.7%) and $H_{7\beta}$ (1.27%).



3.1 mg of **m-Me-^{i}Pr-Me2-COT$_S$** was dissolved in 0.75 ml of methanol-d4 and purged with argon gas for 5 minutes. The solution was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). After 30 minutes, ^{1}H NMR showed the formation of **m-Me-^{i}Pr-Me2-ACB$_S$** as the only product.



m-Me-^{i}Pr-Me$_2$-COT$_s$

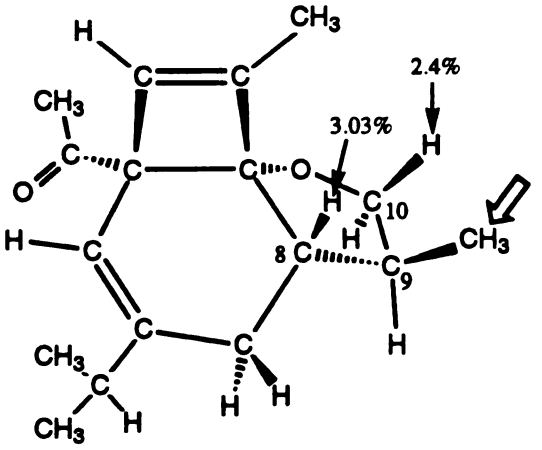
4-Acetyl-6-isopropyl-2,9-dimethyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (m-Me-^{i}Pr-Me$_2$-ACB$_S$):

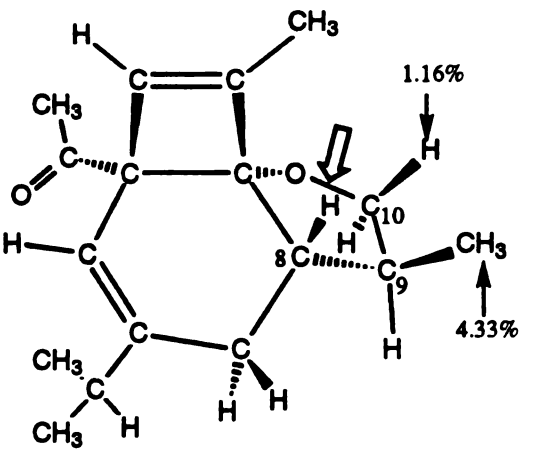
^{1}H NMR (CD$_3$OD) (500 MHz): δ 1.0 (d, J = 6.41 Hz, 3H, C$_9$-Me), 1.01 (d, J = 6.85 Hz, 3H, isopropyl CH$_3$), 1.03 (d, J = 6.85 Hz, 3H, isopropyl CH$_3$), 1.74 (d, J = 1.57, 3H Hz, C$_2$-Me), 1.87 (ddd, J = 10.99, 5.44, 2.43 Hz, 1H, H$_8$), 2.04 (ddd, J = 16.79, 5.52, 2.87 Hz, 1H, H$_7$), 2.11 (s,3 H, CH$_3$CO) 2.13 (m, 1H, H$_9$), 2.18 (dd, J = 16.79, 2.43 Hz, 1H, H$_7$), 2.27 (broad septet, J = 6.85 Hz, 1H, isopropyl methine), 3.31 (dd, J = 9.94, 7.95 Hz, 1H, H$_{10}$), 3.86 (dd, J = 7.95, 7.95 Hz, 1H, H$_{10}$), 5.42 (dd, J = 2.8, 0.90 Hz, 1H, H$_5$), 5.87 (q, J = 1.54 Hz, 1H, H$_3$)

Homonuclear Decoupling NMR Experiment:

Irradiation of proton at 2.27 ppm caused the doublet of doublets (dd) at 5.42 ppm to appear as a doublet, doublet at 1.01 ppm to appear as a singlet and doublet at 1.03 ppm to appear as a singlet. Irradiation of olefinic proton at 5.42 ppm caused the doublet of doublets of doublets (ddd) at 2.04 ppm to appear as a doublet of doublets (dd). Irradiation of methyl groups at ~ 1.02 ppm caused the septet at 2.27 ppm to appear as a broad singlet .

The stereochemistry of **Me-iPr-M2-ACBt** was determined using ^{1}NMR nOe experiments at 25°C (methanol-d4, 500 MHz). Irradiation of the methyl group at C_9 (1.0 ppm) induced enhancement of H_8 (3.03%) and $H_{10\beta}$ (2.4%) while irradiation of H_8 (1.87 ppm) caused enhancement of the methyl group at 1.0 ppm (4.33%) and $H_{10\beta}$ (1.16%).



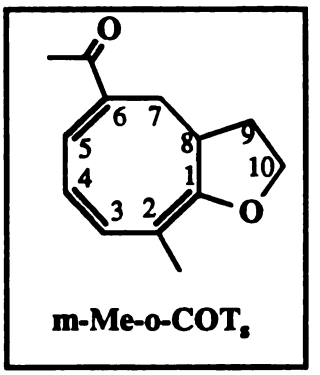


Photolysis of m-Me-oBA:

In an NMR tube, 1.0 mg of **m-Me-oBA** was dissolved in 0.75 ml benzene-d_6 and purged with argon gas for 5 minutes. The solution was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). After 100 minutes irradiation (75% conversion), ^{1}H NMR showed the formation of new peaks corresponding to 6-acetyl-2-methyl-11-oxatricyclo [6.3.0.0^{3,6}]undeca-1,4-diene (**m-Me-o-LCB$_{s,anti}$**) as the only product (90% yield with respect to reacted starting material). When a catalytic amount of *p*-toluenesulfonic acid was added, yellow color developed immediately. ^{1}H NMR showed that peaks corresponding to **m-Me-o-LCB$_{s,anti}$**

had totally disappeared with the formation of new peaks corresponding to 6-acetyl-2-methyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Me-o-COT$_S$**).

A 0.3 g sample of **m-Me-oBA** in 150 ml dry benzene was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm) for 5 hours. After removing the solvent under vacuum, ^{1}H NMR analysis showed the formation of **m-Me-o-LCB$_{S,anti}$**. After preparative TLC (10% ethylacetate/hexanes), 0.073 g of **m-Me-o-COT$_S$** was isolated.



m-Me-o-COT$_s$

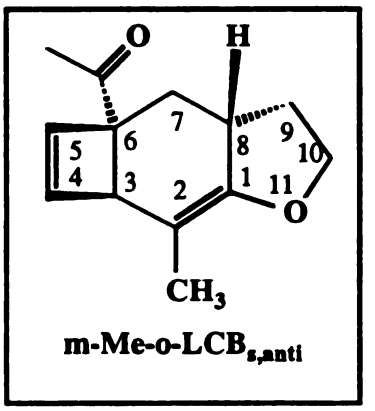
6-Acetyl-2-methyl-11- oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Me-o-COT$_S$**):

^{1}H NMR (C_6D_6) (300 MHz): δ 1.20 (dddd, J = 12.91, 6.6, 3.3, 3.3 Hz, 1H, H_9), 1.59 (dddd, J = 12.55, 9.34, 8.25, 7.42 Hz, 1H, H_9), 1.87 (s, broad, 3H, C_2-Me), 1.92 (s, 3H, CH_3CO), 2.58 (broad, dd, J = 17.3, 3.84 Hz, 1H, H_7), 2.68 (broad, dd, J = 17.3, 10.17 Hz, 1H, H_7), 2.94 (m, 1H, H_8), 3.64 (ddd, J = 8.52, 8.52, 3.52 Hz, 1H, H_{10}), 3.81 (ddd, J = 8.79, 8.79, 6.32 Hz, 1H, H_{10}), 5.48 (dd, J = 12.36, 6.59 Hz, 1H, H_4), 5.94 (d, J = 12.36 Hz, 1H, H_3), 6.61 (broad, d, J = 6.59 Hz, 1H, H_5)

^{1}H NMR ($CDCl_3$) (300 MHz): δ 1.71 (broad, s, 3H, C_2-Me), 1.86 (dddd, J = 12.22, 6.17, 2.96, 2.96 Hz, 1H, H_9), 2.22 (dddd, J = 12.22, 9.70, 8.50, 7.47 Hz, 1H, H_9), 2.33 (s, 3H, CH_3CO), 2.67(broad, d, J = 6.81 Hz, 2H, H_7), 3.2 (m, 1H, H_8), 4.22 (ddd, J = 8.56, 8.56, 3.05 Hz, 1H, H_{10}), 4.38 (ddd, J = 9.70, 8.67, 6.29 Hz, 1H, H_{10}),

5.90 (dd, J = 12.37, 6.8 Hz, 1H, H_4), 6.04 (d, J = 12.36 Hz, 1H, H_3), 7.0 (broad, d, J = 6.80 Hz, 1H, H_5),.

In an NMR tube, 3.1 mg of **m-Me-o-COT$_S$** in 0.75 ml of benzene-d_6 was irradiated at λ = 365 nm for 40 minutes. ^{1}H NMR analysis showed the complete disappearance of **m-Me-o-COT$_S$** peaks with the appearance of peaks corresponding to **m-Me-o-LCB$_{S,anti}$**.



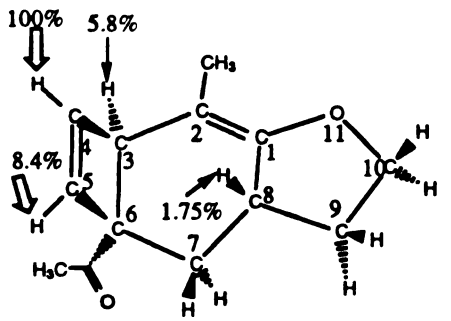
m-Me-o-LCB$_{s,anti}$

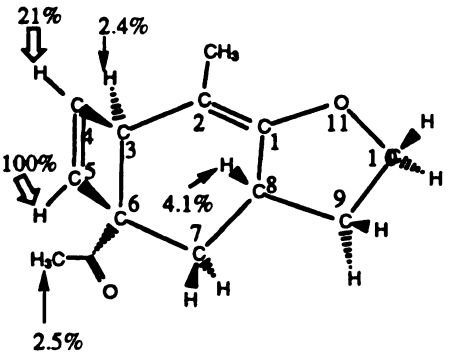
6-Acetyl-2-methyl-11-oxatricyclo[7.2.0.0^{3,6}]undeca-1,4-diene (m-Me-o-LCB$_{S,anti}$):

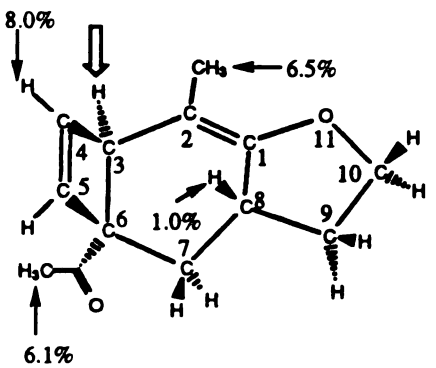
^{1}H NMR (C_6D_6) (500 MHz): δ 1.23 (dddd, J = 11.71, 11.71, 11.27, 8.39 Hz, 1H, H_9), 1.43 (dd, J = 12.95, 11.93 Hz, 1H, H_7), 1.50 (dddd, J = 11.71, 7.73, 5.52, 0.89 Hz, 1H, H_9), 1.79 (dd, J = 12.95, 7.96 Hz, 1H, H_7), 1.81 (d, J = 2.21 Hz, 3H, C_2-Me), 1.85 (s, 3H, CH_3CO), 2.1 (m, 1H, H_8), 3.17 (broad, s, 1H, H_3), 3.52 (ddd, J = 11.93, 8.4, 5.52 Hz, 1H, H_{10}), 3.82 (ddd, J = 8.4, 8.4, 0.88 Hz, 1H, H_{10}), 5.81 (d, J = 2.88 Hz, 1H, H_5), 5.93 (dd, J = 2.88, 0.89 Hz, 1H, H_4)

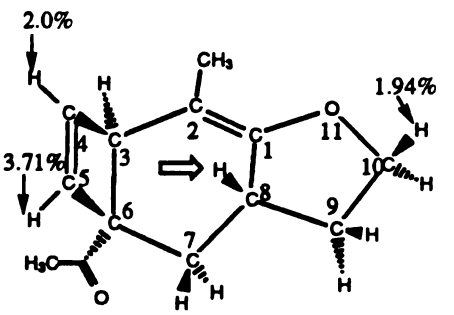
nOe Experiment:

The stereochemistry of **m-Me-o-LCB$_{s,anti}$** was determined using ^{1}H NMR nOe experiments at 15°C (benzene-d_6, 500 MHz). Irradiation of H_4 (H_5 was partially irradiated) led to the enhancement of H_3 (5.8%) and H_8 (1.75%). Irradiation of H_5 (H_4 was partially irradiated) induced enhancement of H_3 (2.4%), H_8 (4.1%) and the acetyl group (2.5%). Irradiation of H_3 led to the enhancement of H_4 (8.0%), CH_3 (6.5%), acetyl group (6.1%) and H_8 (1.0%). Irradiation of H_8 induced enhancement of H_4 (2.0%), H_5 (3.71%), $H_{10\beta}$ (1.94%).









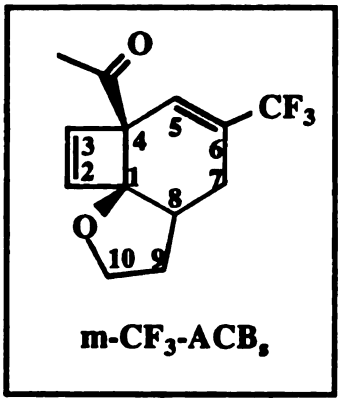
Photolysis of m-CF_3-pBA:

In an NMR tube, 1.8 mg of **m-CF_3-pBA** was dissolved in 0.75 ml of methanol-d4 and purged with argon for 5 minutes. It was irradiated using Pyrex filtered light ($\lambda \geq 290$ nm). After 80 minutes of irradiation, ^{1}H NMR analysis

showed the formation of 4-acetyl-6-trifluoromethyl-11-oxatricyclo[6.3.0.$0^{1,4}$]-undeca-2,5-diene (**m-CF_3-ACB_S**).

The irradiation was also carried out in benzene, in an NMR tube, 1.8 mg of **m-CF_3-pBA** was dissolved in 0.75 ml of benzene-d_6 and purged with argon for 5 minutes. It was irradiated using Pyrex filtered light ($\lambda \geq 290$ nm). After 145 minutes of irradiation, ^{1}H NMR analysis showed the formation of 4-acetyl-6-trifluoromethyl-11-oxatricyclo[6.3.0.$0^{1,4}$]undeca-2,5-diene (**m-CF_3-ACB_S**) and 4-acetyl-2-trifluoromethyl-11-oxatricyclo [6.3.0.$0^{3,6}$]undeca-1,4-diene (**m-CF_3-$LCB_{a,anti}$**) in a ratio of ~ 2 : 1 (NMR integration of doublets at 5.9 and 5.46 ppm)

In an NMR tube, 4.0 mg of **m-CF_3-pBA** in 0.9 ml of benzene-d_6 was purged with argon, placed in ice-water bath, and irradiated for two hours using Pyrex-filtered light. ^{1}H NMR showed the formation of **m-CF_3-ACB_S** with traces of **m-CF_3-$LCB_{a,anti}$**.

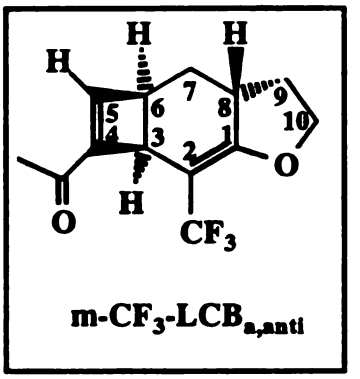


m-CF_3-ACB_s

4-Acetyl-6-trifluoromethyl-11-oxatricyclo[6.3.0.$0^{1,4}$]undeca-2,5-diene (m-CF_3-ACB_S):

^{1}H NMR (C_6D_6) (300 MHz) (partial spectrum): δ 6.48 (m, 1H, H_5), 5.89 (d, J = 2.8 Hz, 1H, H_3), 5.46 (d, J = 2.8 Hz, 1H, H_2), 2.01 (s, 3H, CH_3CO)

^{1}H NMR (CD_3OD) (300 MHz) (partial spectrum): δ 2.2 (s, 3H, CH_3CO) 6.49 (d, J = 2.96 Hz, 1H, H_3), 6.46 (m, 1H, H_5), 6.33 (d, J = 2.96 Hz, 1H, H_2)



m-CF_3-$LCB_{a,anti}$

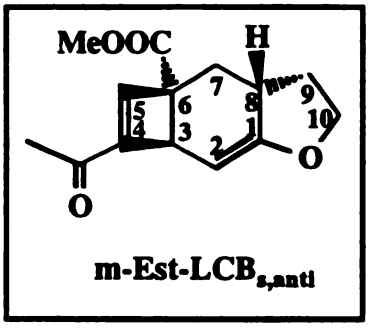
4-Acetyl-2-trifluoromethyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (m-CF_3-$LCB_{a,anti}$):

^{1}H NMR (C_6D_6) (300 MHz): δ 0.55 (ddd, J = 12.81, 11.88, 6.02 Hz, 1H, H_7), 0.88 (tdd, J = 11.88, 11.27, 8.66 Hz, 1H, H_9), 1.23 (m, 1H, H_9), 1.44 (ddd, J = 12.78, 5.21, 1.55 Hz, 1H, H_7), 1.80 (m, 1H, H_8), 1.88 (s, 3H, CH_3CO) 2.53 (ddt, J = 6.06, 4.39, 1.43 Hz, 1H, H_6), 3.28 (ddd, J = 11.71, 8.75, 5.82 Hz, 1H, H_{10}), 3.65 (td, J = 8.8, 1.0 Hz, 1H, H_{10}), 3.77 (d, J = 4.39 Hz, 1H, H_3), 5.91 (d, J = 1.37 Hz, 1H, H_5),.

Photolysis of m-Est-pBA:

In an NMR tube, 1.4 mg of **m-Est-pBA** was dissolved in 0.75 ml of benzene-d_6 and purged with argon for 5 minutes. It was irradiated using Pyrex filtered-light (λ ≥ 290 nm). After 45 minutes, ^{1}H NMR showed the formation of 4-acetyl-6-methoxycarbonyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (**m-Est-$LCB_{s,anti}$**) and 4-acetyl-6-methoxycarbonyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (**m-Est-ACB_s**) with a ratio of 1 : 1 (NMR integration of s at 6.22 and

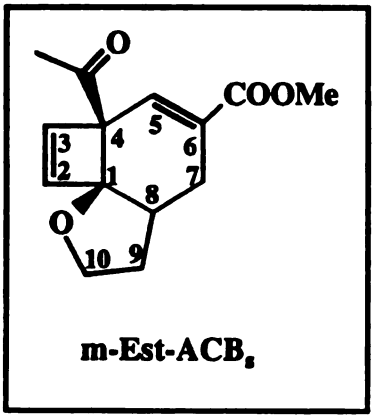
doublet at 5.6 ppm). When catalytic amount of *p*-toluenesulfonic acid was added, the solution color turned yellow and ^{1}H NMR showed the formation of 4-acetyl-6-methoxycarbonyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (**m-Est-COT$_S$**) with the disappearance of **m-Est-LCB$_{S,anti}$** and **m-Est-ACB$_S$**.



m-Est-LCB$_{s,anti}$

4-Acetyl-6-methoxycarbonyl-11-oxatricyclo[6.3.0.0^{3,6}]undeca-1,4-diene (m-Est-LCB$_{S,anti}$):

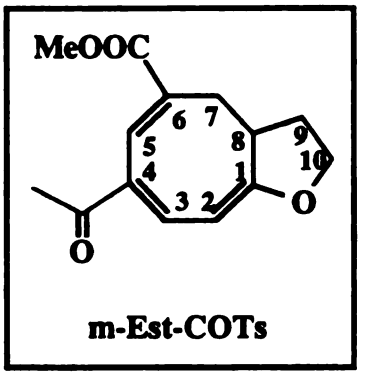
^{1}H NMR (C_6D_6) (300 MHz) (partial spectrum): δ 6.22 (dd, *J* = 6.7, 2.4 Hz, 1H, H_2), 5.38 (s, 1H, H_5)



m-Est-ACB$_S$

4-Acetyl-6-methoxycarbonyl-11-oxatricyclo[6.3.0.0^{1,4}]undeca-2,5-diene (m-Est-ACB$_S$):

^{1}H NMR (C_6D_6) (300 MHz) (partial spectrum): δ 5.59 (d, J = 2.8 Hz, 1H, H_3), 5.98 (dd, J = 2.8, 0.54 Hz, 1H, H_2), 7.24 (dd, J = 2.65, 0.60 Hz, 1H, H_5)



m-Est-COTs

4-Acetyl-6-methoxycarbonyl-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (m-Est-COT$_S$):

^{1}H NMR (C_6D_6) (300 MHz) (partial spectrum): δ 5.46 (dd, J = 8.8, 2.0 Hz, 1H, H_2), 6.87 (d, J = 8.8 Hz, 1H, H_3), 8.1 (s, 1H, H_5)

Photolysis of OMe-m-AP:

In an NMR tube, 1.2 mg of **OMe-m-AP** was dissolved in 0.75 ml of benzene-d_6 and purged with argon gas for 5 minutes. The solution was irradiated with Pyrex-filtered light ($\lambda \geq 290$ nm) ^{1}H NMR analysis showed the gradual disappearance of the starting material with the appearance of very broad signals between 0.3 and 3.5 ppm. Starting material was consumed in about 4 hours.

Photolysis of o-Ac-TB-H:

In an NMR tube, 1.1 mg of **o-Ac-TB-H** was dissolved in 0.75 ml of benzene-d_6 and purged with argon gas for 5 minutes. The solution was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). ^{1}H NMR showed the disappearance of peaks corresponding to starting material with the appearance of new peaks in both the aromatic and aliphatic regions. No peaks corresponding to olefinic protons were observed.

Photolysis of p-Ac-TB-Me:

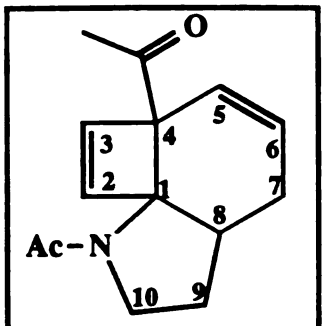
In an NMR tube, 1.1 mg of **p-Ac-TB-Me** was dissolved in 0.75 ml of methanol-d4 and purged with argon gas for 5 minutes. The solution was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). ^{1}H NMR showed that no reaction even after 20 hours of irradiation.

Photolysis of p-NH-AP:

In an NMR tube, 1.2 mg of **p-NH-AP** was dissolved in 0.75 ml of methanol-d4 and purged with argon gas for 5 minutes. The solution was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). ^{1}H NMR Showed that no reaction even after 50 hours of irradiation.

Photolysis of p-NAc-AP:

In an NMR tube 1.3 mg of **p-NAc-AP** was dissolved in 0.75 ml of methanol-d4 and purged with argon gas for 5 minutes. The solution was irradiated for 30 minutes using Pyrex-filtered light ($\lambda \geq 290$ nm). ^{1}H NMR showed the formation of *N*-acetyl-(4-acetyl-11-azatricyclo[6.3.0.$0^{1,4}$]undeca-2,5-diene) (**p-NAc-AP-ACB**) in low chemical yield.



p-NAc-ACB

N-acetyl-(4-acetyl-11-azatricyclo[6.3.0.$0^{1,4}$]undeca-2,5-diene) (p-NAc-ACB):

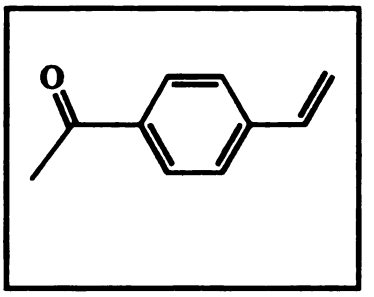
^{1}H NMR (CD_3OD) (300 MHz) (Partial spectrum): δ 1.95 (s, 3H, CH_3CON-), 2.3 (s, 3H, CH_3CO), 5.52 (m ,1H, H_5), 5.86 (m, 1H, H_6), 6.1 (d, J = 2.84 Hz, 1H, H_3), 6.37 (d, J = 2.84 Hz, 1H, H_2)

Photolysis of p-Thio-AP:

In an NMR tube 1.3 mg of **p-Thio-AP** was dissolved in 0.75 ml of benzene-d_6 and purged with argon gas for 5 minutes. The solution was irradiated for 30 minutes using Pyrex-filtered light ($\lambda \geq 290$ nm). ^{1}H NMR Showed the formation of 3-(4-acetylphenyl)tetrahydrothiophene, 4-acetylstyrene and 4-acetyl-α-methylstyrene.

A 0.62 g sample of **p-Thio-AP** in 200 ml of dry benzene was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm) for 3 hours. After removing the solvent under vacuum, ^{1}H NMR analysis showed the formation of three products with the disappearance of starting material. Products were separated using preparative TLC (10% ethylacetate/hexanes). ^{1}H NMR analysis showed that these products are; 4-acetylstyrene, 4-acetyl-α-methylstyrene and 3-(4-acetylphenyl)tetrahydrothiophene. 4-Acetylstyrene and 4-acetyl-α-methylstyrene were not separated

from each other. ^1H NMR was taken of the mixture while mass spectra and hi-resolution mass spectra were done by the aid of GC separation.

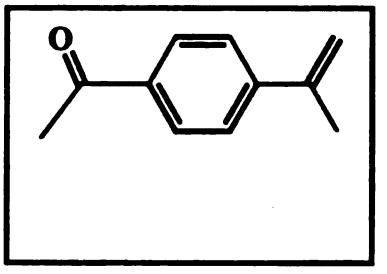


4-Acetylstyrene:

^1H NMR ($CDCl_3$) (500 MHz): δ 2.579 (s, 3H, CH_3CO), 5.38 (dd, *J* = 10.82, 0.66 Hz, 1H), 5.88 (dd, *J* = 17.45, 0.66 Hz, 1H), 6.74 (dd, *J* = 17.45. 10.82 Hz, 1H), 7.47 (d, *J* = 8.17 Hz, 2H), 7.91 (d, *J* = 8.17 Hz, 2H)

MS (m/e): 146 (M^+), 131 (base), 103, 77, 51, 43

Hi-Res MS: $C_{10}H_{10}O$, Calculated: 146.0732, Found 146.0736

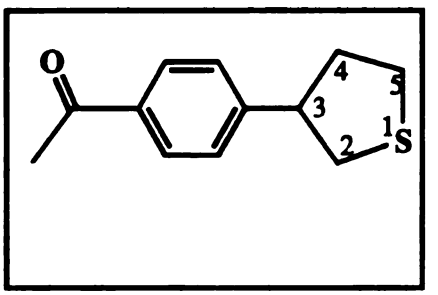


4-Acetyl-α-methylstyrene:

^{1}H NMR ($CDCl_3$) (500 MHz): δ 2.16 (dd, J = 1.33, 0.66 Hz, 3H, CH_3), 2.583 (s, 3H, CH_3CO) 5.19 (dq, J = 1.33, 1.33 Hz, 1H), 5.46 (dq, J = 1.33, 0.66 Hz, 1H), 7.54 (d, J = 8.17 H, 2H), 7.91 (d, J = 8.17 Hz, 2H)

MS (m/e): 160 (M^+), 145 (base), 115, 91, 63, 51, 43

Hi-Res MS: $C_{11}H_{12}O$, Calculated: 160.0888, Found 160.0889



3-(4-Acetylphenyl)tetrahydrothiophene:

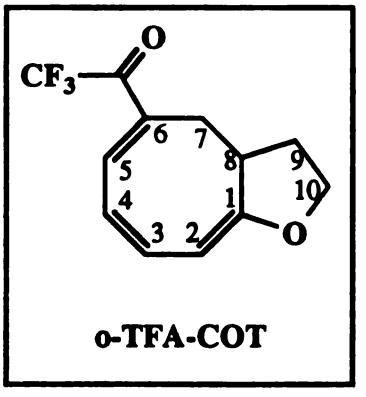
^{1}H NMR (CD_3OD) (500 MHz): δ 2.07 (dddd, J = 12.37, 10.09, 9.28, 7.29 Hz, 1H, H_4), 2.41 (dddd, J = 12.37, 5.95, 5.62, 3.76 Hz, 1H, H_4), 2.58 (s, 3H, CH_3CO), 2.90 (dd, J = 10.38, 9.28 Hz, 1H, H_2), 2.95 (ddd, J = 10.39, 6.9, 3.75 Hz, 1H, H_5), 2.96 (ddd, J = 10.39, 9.4, 5.95 Hz, 1H, H_5), 3.15 (dd, J = 10.38, 9.28 Hz, 1H, H_2), 3.42 (dddd, J = 10.09, 9.28, 6.85, 5.62 Hz, 1H, H_3), 7.45 (d, J = 8.15 Hz, 2H), 7.95 (d, J = 8.15 Hz, 2H)

MS (m/e): 206 (M^+), 191, 163, 145, 115, 103, 91, 77. 60, 43

Photolysis of o-TFA-AP:

In an NMR tube 1.5 mg of **o-TFA-AP** was dissolved in 0.75 ml of benzene-d_6 and purged with argon for 5 minutes. It was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm). After 15 minutes of irradiation (~70% conversion), ^1H NMR.showed the formation of 6-α,α,α-trifluoroacetyl-11- oxabicyclo[6.3.0]-undeca-1,3,5-triene (**o-TFA-COT$_S$**).

A 1.0 g sample of **o-TFA-AP** in 500 ml dry benzene was irradiated using Pyrex-filtered light ($\lambda \geq 290$ nm) for 4 hours. Solvent was removed under vacuum. The mixture was purified by column chromatography (silica gel, 10% ethyl acetate/hexanes) to give 0.38 g of **o-TFA-COT$_S$**.



o-TFA-COT

6-(α,α,α-Trifluoroacetyl)-11-oxabicyclo[6.3.0]undeca-1,3,5-triene (o-TFA-COT$_S$):

^1H NMR ($CDCl_3$) (300 MHz): δ 1.91 (dddd, J = 11.71, 10.92, 10.92, 8.09 Hz, 1H, H_9), 2.3 (dd, J = 13.52, 7.96 Hz, 1H, H_7), 2.34 (m, 1H, H_9), 2.7 (m, 1H, H_8), 3.12 (d, J = 13.52, 1.53 Hz, 1H, H_7), 4.10 (ddd, J = 10.44, 8.79, 5.55 Hz, 1H, H_{10}), 4.20 (ddd, J = 8.52, 8.52, 2.19 Hz, 1H, H_{10}), 5.46 (dd, J = 9.5, 1.98 Hz, 1H, H_2), 5.83 (dd, J =

13.25, 6.80 Hz, 1H, H_4), 6.64 (dd, J = 13.25, 9.50 Hz, 1H, H_3), 7.29 (d, J = 6.80 Hz, 1H, H_5)

^{1}H NMR (C_6H_6) (300 MHz): δ 1.12 (dq, J = 7.97, 11.26 Hz, 1H, H_9), 1.5 (m, 1H, H_9), 1.98 (dd, J = 13.11, 8.51 Hz, 1H, H_7), 2.1 (broad q, J = 8.97 Hz, 1H, H_8), 2.83 (d, J = 13.11 Hz, 1H, H_7), 3.35(ddd, J = 10.71, 8.79, 5.77 Hz, 1H, H_{10}), 3.46 (dt, J = 2.2, 8.79 Hz, 1H, H_{10}), 5.38 (dd, J = 13.31, 7.00 Hz, 1H, H_4), 5.45 (dd, J = 9.45, 2.12 Hz, 1H, H_2), 6.88 (dd, J = 13.31, 9.45 Hz, 1H, H_3), 7.18 (broad d, J = 7.00 Hz, 1H, H_5)

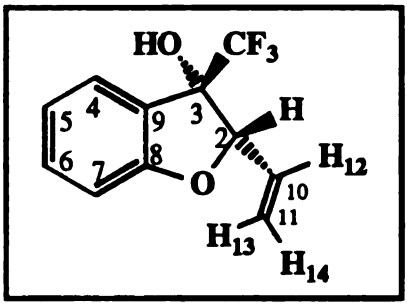
^{13}C NMR (C_6D_6) (75 MHz): δ 29.04, 32.42, 43.26, 68.62, 97.13, 117.71 (q, J = 291 Hz), 117.99, 134.18, 134.44, 143.99 (q, J = 3.68 Hz), 172.07, 180.00 (q)

Photochemistry of **o-PTFAc**

1. In benzene

In an NMR tube, 2.7 mg of **o-PTFAc** was dissolved in 0.75 ml of benzene-d_6, purged with argon for 5 minutes and irradiated with Pyrex-filtered light ($\lambda \geq$ 290 nm). After 35 minutes, ^{1}H NMR showed the complete disappearance of the starting material and the appearance of signals corresponding to two new products in a ratio of 9:1 (GC and NMR integration of the two doublet of triplets at 5.23 and 5.28 ppm). The major isomer was identified as 3-hydroxy-3-trifluoromethyl-2-vinyl-2,3-dihydro-benzofuran from its ^{1}H NMR spectrum. Preparatory scale photolysis was carried out to isolate the product. **o-PTFAc** (0.5 g) was dissolved in dry benzene (500 ml) and irradiated using Pyrex-filtered light. The reaction progress was monitored by TLC. After 6 hours irradiation, solvent was evaporated, and the product was purified using dry column flash

chromatography (5% ethylacetate/hexanes) to give 3-hydroxy-3-trifluoromethyl-2-vinyl-2,3-dihydro-benzofuran (0.274 g, 55%)



3-Hydroxy-3-trifluoromethyl-2-vinyl-2,3-dihydro-benzofuran:

^{1}H NMR (C_6D_6) (500 MHz): δ 1.7 (s, 1H, OH, disappears by adding D_2O), 4.99 (dt, J = 6.58, 1.24 Hz, 1H, H_2), 5.02 (dt, J = 10.7, 1.34 Hz, 1H, H_{14}), 5.23 (dt, J = 17.28, 1.44 Hz, 1H, H_{13}), 5.69 (ddd, J = 17.27, 10.69, 6.58 Hz, 1H, H_{12}), 6.64 (dt, J = 1.05, 7.4 Hz, 1H, H_5), 6.71 (dt, J = 8.23, 0.72 Hz, 1H, H_7), 6.94 (ddd, J = 8.23, 7.41, 1.2 Hz, 1H, H_6), 7.25 (broad d, J = 7.25 Hz, 1H, H_4)

^{1}H NMR ($CDCl_3$) (300 MHz): δ 2.45 (broad singlet) 5.18 (dt, J = 6.42, 1.17 Hz, 1H, H_2), 5.5 (dt, J = 10.59, 1.23 Hz, 1H, H_{14}), 5.64 (dt, J = 17.31, 1.34 Hz, 1H, H_{13}), 6.01 (ddd, J = 17.19, 10.71, 6.6 Hz, 1H, H_{12}), 6.92 (broad d, J = 8.16 Hz, H_7), 6.99 (dt, J = 0.84, 7.55 Hz, 1H, H_5), 7.35 (ddd, J = 8.25, 7.5, 1.41 Hz, 1H, H_6), 7.47 (broad d, J = 7.68 Hz, 1H, H_4),

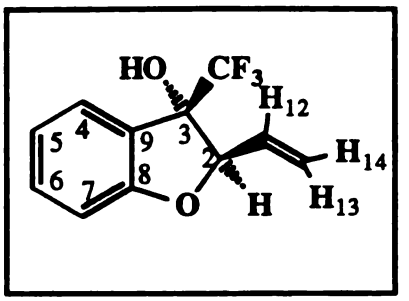
^{13}C NMR ($CDCl_3$) (125 MHz): δ 81.2 (q, J = 30.5 Hz, C_3), 85.82 (C_2), 110.94, 121.55, 121.72, 123.38, 124.57 (q, J = 282.25, CF_3), 125.02, 129.95, 132.36, 160.08

2. In benzene-pyridine

In an NMR tube, 3.1 mg of **o-PTFAc** and two drops of pyridine-d_5 were dissolved in 0.75 ml of benzene-d_6, purged with argon for 5 minutes and irradiated with Pyrex-filtered light ($\lambda \geq 290$ nm). After 150 minutes, ^{1}H NMR showed the formation of *Z*- and *E*-3-hydroxy-3-trifluoromethyl-2-vinyl-2,3-dihydro-benzofuran in a ratio of 1.2 : 1 (9 : 1 in the absence of pyridine). The two isomers were identified from their ^{1}H NMR as a mixture and by comparison to the spectrum of the isolated *Z*-isomer in benzene-d_6 up on the addition of two drops of pyridine-d_5. Determination of the stereochemistry of the products was based on the fact that the *E*-isomer has H_2 anti to the CF_3 group. This allowed a through bonding W-type coupling of 1.28 Hz between the fluorine atoms and H_2. Also, H_{12} is closer to the fluorine atoms in the *E*-isomer than in the *Z*-isomer which allowed a through space coupling of 2.47 Hz between the fluorine atoms and H_{12}. These couplings were not observed in the spectrum of the *Z*-isomer

Z-3-Hydroxy-3-trifluoromethyl-2-vinyl-2,3-dihydro-benzofuran:

^{1}H NMR (C_6D_6+2 drops pyridine-d_6) (300 MHz): δ 5.2 (dt, J = 10.72, 1.38 Hz, 1H, H_14), 5.3 (dt, J = 6.53, 1.18 Hz, 1H, H_2), 5.43 (dt, J = 17.18, 1.45 Hz, 1H, H_{13}), 6.33 (ddd, J = 17.16, 10.5, 6.66 Hz, 1H, H_{12}), 6.65 (dt, J = 1.0, 7.48 Hz, 1H, H_5), 6.77 (broad d, J = 8.24 Hz, 1H, H_7), 6.96 (ddd, J = 8.3, 7.39, 1.4 Hz, 1H, H_6), 7.52 (broad d, J = 7.57 Hz, 1H, H_4)



E-3-Hydroxy-3-trifluoromethyl-2-vinyl-2,3-dihydro-benzofuran:

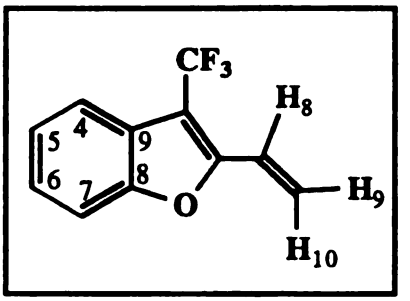
^{1}H NMR (C_6D_6+2 drops pyridine-d_6) (300 MHz): δ 5.15 (dt, *J* = 10.44, 1.35 Hz, 1H, $H_1$4), 5.33 (d of sextet, *J* = 7.14, 1.28 Hz, 1H, H_2), 5.48 (dt, *J* = 17.3, 1.38 Hz, 1H, $H_1$3), 6.22 (dddq, *J* = 17.58, 10.44, 7.14, 2.47 Hz, 1H, $H_1$2), 6.59 (dt, *J* = 0.83, 7.42 Hz, 1H, H_5), 6.81 (broad d, *J* = 8.24, 1H, H_7), 6.98 (dt, *J* = 1.37, 8.24 Hz, 1H, H_6), 7.56 (broad d, *J* = 7.69 Hz, 1H, H_4)

In order to compare the spectra of the two isomers in absence of pyridine, solvent was removed under vacuum and sample was dissolved in benzene-d_6.

^{1}H NMR (C_6D_6) (300 MHz): δ 1.8 (singlet, 1H, disappears by adding D_2O), 4.76 (d of sextet, *J* = 7.26, 1.26 Hz, 1H, H_2), 5.06 (dt, *J* = 10.4, 1.13 Hz, 1H, $H_1$4), 5.33 (dt, *J* = 17.07, 1.38 Hz, 1H, $H_1$3), 5.96 (dddq, *J* = 17.2, 10.34, 7.35, 2.38 Hz, 1H, $H_1$2), 6.65 (dt, *J* = 1.0, 7.5 Hz, 1H, H_5), 6.72 (broad d, *J* = 8.2 Hz, 1H, H_7), 6.95 (ddd, *J* = 8.1, 7.5, 1.44 Hz, 1H, H_6), 7.19 (broad d, *J* = 7.9 Hz, 1H, H_4)

In order to further establish the structure of *E*-3-hydroxy-3-trifluoromethyl-2-vinyl-2,3-dihydro-benzofuran, it was dehydrated using an acid. A solution of the compound in chloroform-d was treated with two drops of

trifluoroacetic acid. ^1H NMR analysis showed no change in the spectrum. Then two drops of trifluoromethane sulfonic acid were added, this time ^1H NMR analysis showed the total disappearance of starting material with the formation of the dehydration product; 3-trifluoromethyl-2-vinyl-benzofuran.



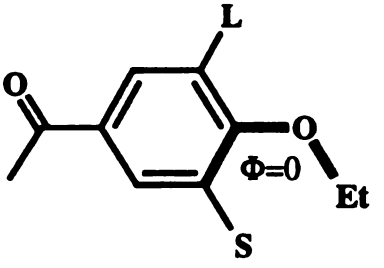
3-Trifluoromethyl-2-vinyl-benzofuran:

^1H NMR ($CDCl_3$) (300 MHz): δ 5.62 (dd, *J* = 11.26, 1.1 Hz, 1H. H_9), 6.2 (dd, *J* = 17.35, 1.18 Hz, 1H, H_{10}), 6.87 (ddq, *J* = 17.34, 11.3, 1.13 Hz, 1H, H_8), 7.28 (dt, *J* = 1.2, 7.48 Hz, 1H), 7.36 (dt, *J* = 1.4, 7.37 Hz, 1H), 7.48 (dd, *J* = 8.08, 1.03 Hz, 1H), 7.64 (broad d, *J* = 7.76 Hz, 1H),

Computational Analysis

The ground state geometry of some of the photoproducts was optimized using the Cache implementation of MOPAC.[121] Output structure was altered by varying some dihedral angles and then redoing the calculation in order to distinguish between local minima and the global minimum for each compound. The following parameters were used: Optimized geometry, singlet , and AM1[122]

For some cyclooctatrienes, geometries were optimized for their ground states then for their excited singlet states. Charge distribution on various atoms was obtained from the Cache output archive file. The following parameters were used: Optimized geometry, excited singlet and AM1



Rotational barriers around Ar—OEt bond of some meta-substituted para-ethoxyacetophenones were calculated for their triplet states. The ground state geometry of each compound was first optimized. An optimized search was done by computing energies for various dihedral angles of rotation around the benzene-oxygen bond. A dihedral angle, $\Phi = 0$ was assumed for the ethoxy group in the plane of the benzene ring and syn to the smaller ortho group. Φ was varied by 15 degrees from 0^{o} to 360^{o}. For 4-ethoxy-3-isopropyl-5-methylacetophenone, search was also done with varying Φ every 5 degrees between 45^{o} and 135^{o}. The following parameters were used: Optimized search, reaction coordinate, triplet using UHF, AM1 and noanci key word.

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