
Among various modifications of calix[4]arenes, the calixarene derived bis(spirodienones) (figure 2.1) are an interesting class of molecules discovered by Biali et al.\(^1\) and are obtained by the oxidative cyclization of the four phenolic hydroxyl groups of \textit{p-tert}-butylcalix[4]arene. The molecules are bestowed with two carbonyl and two ether functionalities in an alternant or non-alternant fashion as part of a 14-membered irregular cavity making them potential candidates as ionophores or as precursors for designing modified calixarenes. They have been successfully utilized by the parent group (Biali’s group) as synthetic intermediates for modifying calixarenes at the intraannular, extraannular and bridging methylene positions, a detailed account of which was presented in the introductory chapter. If we look at the structures of calix[4]bis(spirodienones), they have a reactive diene part which can be utilized for further modification through cycloaddition reactions. It is clear from the literature that this route has received only scant attention in this regard. Thus with the aim of developing new methodologies for the synthesis of new calixarene derived macrostructures we embarked upon a systematic study of the cycloaddition chemistry of the bis(spirodienones). The results of our investigation on the reactivity of the bis(spirodienones) towards carbo- and heterodienophiles are presented in this chapter.
The structural resemblance of the cyclohexadienone moieties of bis(spirodienone) towards masked ortho-benzoquinones (MOBs) (figure 2.2) prompted us to carry out a literature survey of the cycloaddition reactions of these simpler molecules for a comparative purpose and the reports encountered are presented in the following section.

2.1 Introduction

2.1.1 Masked ortho-benzoquinones (MOBs)

Masked ortho-benzoquinones (MOBs), which are linearly conjugated cyclohexadienones, can potentially participate in cycloaddition reactions. The double bonds of the diene moiety, being positioned between a carbonyl and an acetal functionality are electronically differentiated and can be elaborated regioselectively in various reactions. Despite their remarkable synthetic potential, MOBs are relatively underexploited in organic synthesis as compared to their counterparts derived from p-benzoquinones. This dearth of MOB chemistry may be attributed to their high reactivity, resulting in great propensity toward dimerization. Encouraged by the unexploited synthetic potential of this class of synthons, Liao et al.\(^2\) have initiated work on the chemistry of MOBs, especially based on their Diels-Alder reactivity, and their major observations are presented in the forthcoming section.
2.1.2 Intermolecular Diels-Alder reactions

The Diels-Alder reaction appears to be the most widely used protocol to synthesize simple and complex ring systems due to its ability of creating up to four contiguous stereogenic centres in a highly stereoselective and predictable manner in a single laboratory operation.\textsuperscript{3-6} MOBs, by virtue of their structure can react as either a diene or a dienophile in Diels-Alder reactions. MOBs 2 can be easily obtained by the oxidation of readily available 2-methoxy phenols 1 with hypervalent iodine reagents\textsuperscript{7} such as (diacetoxy)iodobenzene (DAIB) or phenyliodonium(III) bis(trifluoroacetate) (PIFA) in methanol (scheme 2.1).

\begin{center}
\begin{align*}
\text{OMe} & \quad \text{oxidant} \\
\text{MeOH} & \quad \text{OMe} \\
\text{OH} & \quad \text{OMe}
\end{align*}
\end{center}

Scheme 2.1: Synthesis of MOBs

Simple MOBs are found to be highly reactive and dimerize rapidly to produce dimers 3 in high yields (figure 2.3). It results from the cycloaddition of a molecule of MOB as the diene and C\textsubscript{4}-C\textsubscript{5} double bond of the other as the dienophile.

\begin{center}
\textbf{Figure 2.3: Dimer of MOB}
\end{center}

As the dimerization of MOB and the Diels-Alder reactions between MOB and an external dienophile are competitive reactions, a high dilution technique was employed to prevent/minimize the formation of dimers by generating MOBs \textit{in situ} at low concentration in the presence of large excess of dienophile.\textsuperscript{8}

2.1.2.1 Cycloaddition reaction with electron-deficient olefinic systems

The cycloaddition reaction of MOB 4 with electron-deficient dienophiles such as methyl acrylate and methyl vinyl ketone afforded the
bicyclo[2.2.2]octenone derivatives 5 via endo addition in good to excellent yields (scheme 2.2).9,10

\[
\begin{align*}
\text{Scheme 2.2: Cycloaddition reaction of MOB with electron-deficient dienophiles} \\
\text{Though in principle, there are four possible modes of [4+2] cycloaddition, ortho, anti-adduct (the electron withdrawing group, X is adjacent and anti to the carbonyl function of the bicyclo[2.2.2]octenone moiety) was obtained as the sole product in each case indicating that the Diels-Alder reaction is highly regio- and stereoselective.}
\end{align*}
\]

2.1.2.2 Cycloaddition reaction with electron-rich olefinic systems

Liao et al. further investigated the Diels-Alder reactions of various MOBs with electron-rich dienophiles such as benzyl vinyl ether, dihydrofuran, styrene and phenyl vinyl sulfide. The cycloadditions were both regio- and stereoselective and furnished ortho, anti-adducts 7 as in the case of electron-deficient dienophiles (scheme 2.3).10-12

\[
\begin{align*}
\text{Scheme 2.3: Synthesis of regio- and stereoselective bicyclo[2.2.2]octenones} \\
\text{2.1.2.3 Cycloaddition reaction with furans} \\
\text{Despite its aromaticity, furans participate in Diels-Alder cycloaddition essentially as 4π partners. Nevertheless, MOBs compelled furans to act as dienophiles in Diels-Alder reactions.13,14 In situ generated MOBs reacted with a variety of furans at appropriate temperature in methanol to afford the}
\end{align*}
\]
corresponding cycloadducts 9 with a high degree of regio- and stereoselectivity (scheme 2.4).

![Diagram of Diels-Alder reaction of bis(spirodienones)](image)

Scheme 2.4: Furan as a dienophile in its cycloaddition reaction with MOBs

### 2.1.2.4 Dienophilic behaviour of MOBs

The dienophilic behaviour of MOBs in their reactions with unactivated 1,3-butadiene was observed for the first time by Liao group. The MOBs on reaction with 1,3-butadienes like 2,3,4-trimethyl-penta-1,3-diene 11 provided Diels-Alder adducts 12 and 13. This indicated their dual character as a diene and dienophile in cycloaddition reactions. Furthermore, the transformation of adducts 12 to 13 was effected at 180-220 °C via Cope rearrangement (scheme 2.5).

![Diagram of Diels-Alder reaction of MOBs with the 1,3-diene 11](image)

Scheme 2.5: Diels-Alder reaction of MOBs with the 1,3-diene 11

### 2.1.2.5 Hetero-Diels-Alder reaction

As an extension to carbo-Diels-Alder reaction, Liao group examined the reactivity of MOBs with heterodienophiles. The MOB derived from guaiacol, 14 was treated with nitroso compound derived from N-hydroxycarbamate, to produce highly functionalized heterocycle 15 in excellent yield via facile
hetero-Diels-Alder reactions of transiently generated MOB and nitroso
dienophiles (scheme 2.6).\textsuperscript{16}

![Image](image.png)

\textbf{Scheme 2.6: Cycloaddition reaction of MOB with nitroso compound.}

\textbf{2.2 Statement of the Problem}

It is clear from the above discussion on MOBs that they are interesting
synthetic intermediates used for the construction of a wide variety of
functionalized cyclic systems. It is also interesting to note their dual reactivity
as a diene and as a dienophile in cycloaddition reactions. The
cyclohexadienone moieties present in the calixarene derived bis(spirodienones)
structurally resemble MOBs. The one and only report on the cycloaddition of
bis(spirodienones) cited in the literature is its reaction with benzyne.\textsuperscript{17} This
demonstrates its capability to act as $4\pi$ components in cycloaddition reactions.

Intrigued by the unexploited synthetic potential of this class of synthons,
we embarked on a research program on the "chemistry of
calix[4]bis(spirodienones)" with the main aim of developing new synthetic
methodologies, based on the cycloaddition reactions towards a wide range of
carbo- and heterodienophiles. The results of our attempts validating the
usefulness of the process, leading to multifunctional macrocycles based on
calix[4]arenes are offered in the following passages.

\textbf{2.3 Results and Discussion}

\textbf{2.3.1 Cycloaddition reactions with carbodienophiles}

The calix[4]bis(spirodienones) 16 and 17 used as starting materials
throughout our investigation were synthesized following Biali's procedure
(scheme 2.7).\textsuperscript{17}
Diels-Alder reaction of bis(spirodienones)

Scheme 2.7: Preparation of bis(spirodienones) from p-tert-butylcalix[4]arene

2.3.1.1 Cycloaddition reaction with activated acetylenes: synthesis of calix[4]bis(bicyclo[2.2.2]octadienone) derivatives

Our investigations were initiated by reacting the most stable isomer of the calix[4]bis(spirodienone) 16 with two equivalents of DMAD 18 in anhydrous toluene at ambient conditions. Column chromatography of the reaction mixture on silica gel afforded a single product 19 in quantitative yield (scheme 2.8).

Scheme 2.8: (4+2) Cycloaddition reaction of bis(spirodienone) 16 with DMAD

The product 19 was identified as the (4+2) bis-cycloadduct between bis(spirodienone) and two DMAD units, where the cyclohexadienone moieties functioned as the dienes, by spectroscopic methods. The IR spectrum of 19 showed two strong carbonyl absorptions at 1746 and 1710 cm\(^{-1}\) which were assigned to the ester carbonyls and the ring carbonyls respectively. The \(^1H\) NMR spectrum (figure 2.4) of 19 provided clear indications of the formation of a symmetrical cycloadduct. The salient features of the spectrum pointing towards this were (a) the appearance of the protons marked as H\(_a\) and H\(_b\) as doublets at δ 4.82 and 4.35 respectively showing allylic coupling (\(J = 2.1\) Hz).
(The corresponding protons in the starting material had appeared at δ 5.82 and 6.59 respectively); (b) the methoxy groups of the DMAD part as two singlets at δ 3.87 and 3.79 and (c) identical splitting patterns of the doublets arising from the two pairs of methylene groups in the starting compound and the product 19. The appearance of the aromatic protons as two singlets at δ 7.06 and 6.89 and the tert-butyl protons as two singlets at δ 1.30 and 0.98 further supported the proposed structure.

![Figure 2.4: 1H NMR spectrum of 19](image_url)

The salient features of the 13C NMR spectrum (figure 2.5) include the peaks at (a) δ 166.0 and 163.0 due to the two ester carbonyl groups; (b) δ 192.7 and 77.2 due to the ring carbonyl and the spiro carbon; (c) δ 52.5 and 52.4 corresponding to the two methoxy carbons; (d) δ 34.5 and 34.3 due to the quaternary carbons of the tert-butyl groups; (e) δ 27.2 and 31.7 due to methyl carbons of the tert-butyl group and (f) δ 27.7 and 38.8 assigned to the bridging methylene carbons. The proposed structure was further supported by the FAB mass spectrum which showed the [M+1] ion peak at 929.7 and satisfactory elemental analysis.
Diels-Alder reaction of bis(spirodieneones)

Figure 2.5: $^{13}$C NMR spectrum of 19

While the structure could be arrived at with the spectral data, the stereochemistry at the spirocarbons and the exclusive formation of the exo-exo isomer was confirmed by single crystal X-ray analysis (figure 2.6). A selective approach of the dienophile from the face opposite to the dihydrofuran oxygen (less sterically hindered face) has resulted in the exclusive formation of the exo-exo isomer.

Figure 2.6: Single crystal X-ray structure of compound 19

Subsequent to the cycloaddition reaction with the 1,3-isomer 16 of the bis(spirodieneone), we turned our attention to the cycloaddition of the 1,2-isomer 17. The reaction of 17 with two equivalents of DMAD under the same reaction conditions required roughly 36 h for the completion (scheme 2.9).
But
But But
But But

\[ I = \text{DMAD, toluene, } rt, \text{36 h} \]

**Scheme 2.9: Reaction of bis(spirodienone) 17 with DMAD**

Spectral analysis of the product, particularly the \(^1\)H NMR, revealed that the spectrum matched exactly with that of the compound 19. It may be noted that our result differs from that of the cycloaddition of 16 and 17 with highly reactive benzyne which Biali *et al.* had reported. While both the isomers 16 and 17 readily underwent cycloaddition with benzyne fetching the respective cycloadducts, their cycloaddition with the less reactive DMAD furnished the same cycloadduct 19 in excellent yield. Considering the fact that the isomers exist in equilibrium, an appropriate explanation for this interesting observation could be provided in terms of the rates of the cycloaddition and isomerization reactions of the two isomers. Benzyne being much more reactive than DMAD, readily underwent cycloaddition at a faster rate with both the isomers fetching the respective products. Reaction with DMAD being much more slow, the rate of isomerization would have had an upper hand fetching the same cycloadduct in both the cases.

Upon getting the [4+2] biscycloadduct in quantitative yield in the above reaction, we proceeded further by reacting bis(spirodienone) with various activated acetylenes to check the generality of this process. Accordingly the cycloaddition reaction between 16 and di-tert-butyl acetylenedicarboxylate 20 was investigated. It was found that this reaction proceeded to completion only at the refluxing temperature of toluene. The corresponding bisadduct 21 was isolated in quantitative yield and was fully characterised on the basis of spectral analysis.
Reactions of 16 with unsymmetric acetylenes like methyl propiolate 22 and methyl phenylpropiolate 24 afforded single regioisomers 23 and 25 respectively in excellent yields. The structures of 23 and 25 were confirmed by spectroscopic methods.

The doublet at $\delta$ 7.22 in the $^1$H NMR spectrum of the adduct 23 was assigned to the olefinic proton adjacent to the ester group based on the following observations: (a) on irradiation of the doublet at $\delta$ 7.22 ($J = 6.5$ Hz), the double doublet at $\delta$ 3.84 was reduced to a doublet ($J = 2.3$ Hz). Hence the dd at $\delta$ 3.84 ($J = 6.5$ Hz, 2.3 Hz) was assigned to the bridgehead proton which showed allylic coupling with the olefinic proton adjacent to the tert-butyl group which appeared as doublet at $\delta$ 4.92 ($J = 2.2$ Hz). Similar reactivity was observed with 3-phenyl methylpropiolate 24 to yield a single product 25 as proved by spectral data.

We further extended the reaction to other unsymmetric acetylenes such as ethyl 2-butynoate 26 and methyl 5,5-dimethyl-4-oxo-2-hexynoate 29 under similar conditions. The reaction of bis(spirodiene) 16 with ethyl 2-butynoate 26 under reflux condition for 10 h showed the initial formation of two products, one in major 27 and the other 28 in minor quantities. We observed that as the time proceeded, the proportion of the minor product increased and after a period of 18 h a regioisomeric mixture of the bis(bicyclo[2.2.2]octadienone) derivatives 27 and 28 were obtained in a ratio of 1:1. The isomers were separated by repeated column chromatography. Structures of the compounds were established by spectral data.

The IR spectrum of 27 showed strong absorptions at 1739 and 1697 cm$^{-1}$ due to the ester and enone carbonyl groups. In the $^1$H NMR spectrum, the aromatic protons appeared as singlets at $\delta$ 7.05 and 6.89. The olefinic proton was discernible as a singlet at $\delta$ 4.76. The bridgehead proton appeared at $\delta$ 4.27 along with the -OCH$_2$ protons of the ethyl ester. The methyl group attached to the double bond resonated at a higher $\delta$ value of 2.20. The multiplet at $\delta$ 1.30 was assigned to the methyl group of the ester group. In the $^{13}$C NMR spectrum
the characteristic peaks of enone and ester carbonyls were visible at δ 194.7 and 165.5 respectively. The spirocarbon appeared at δ 78.4 and the methyl carbons at δ 15.7 and 14.7.

A comparison of the spectral data of 27 and 28 showed many similarities. The ester and enone carbonyl absorptions of 28 appeared at 1742 and 1700 cm\(^{-1}\). In the \(^1\)H NMR spectrum the peaks resonated almost in the same region as that of compound 27 except for the bridgehead proton. The bridgehead proton appeared as a singlet at δ 3.59. The \(^13\)C NMR spectrum also closely resembled that of compound 27.

Analogous reactivity was experienced in the reaction of 16 with 29 and furnished an inseparable mixture of regioisomers 30 and 31 in 1:1 ratio. The structure was confirmed by spectral analysis. In the above two cases, the reactions were found to be unselective resulting in two products each. The lack of selectivity obtained may be explained as due to marginal difference in steric demands of the acetylene substituents. Table 2.1 summarizes the results obtained in the cycloaddition reaction of bis(spirodienone) 16 with several electron-deficient acetylenes.

Table 2.1: Generalization of the Diels-Alder reaction of 16 with activated acetylenes

<table>
<thead>
<tr>
<th>Entry</th>
<th>Acetylenes</th>
<th>Time (h)</th>
<th>Product</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(\text{CO}_2\text{Bu}^\prime), (\text{CO}_2\text{Bu}^\prime)</td>
<td>10</td>
<td>[Image of Product 21]</td>
<td>99</td>
</tr>
<tr>
<td>20</td>
<td>(\text{CO}_2\text{Me})</td>
<td>12</td>
<td>[Image of Product 22]</td>
<td>94</td>
</tr>
<tr>
<td>2</td>
<td>(\text{MeO}_2\text{C}), (\text{H})</td>
<td>22</td>
<td>[Image of Product 23]</td>
<td>94</td>
</tr>
</tbody>
</table>


To test whether a decrease in the equivalents of DMAD would result in the formation of the mono rather than the bisadduct, we carried out the reaction by lowering the stoichiometry of DMAD. However, only the bisadduct was isolated along with the unreacted starting compound.

Structural resemblance of bis(spirodienones) with MOBs encouraged us to examine its cycloaddition reactions with electron-rich acetylenes like diphenylacetylene and ethoxyacetylene. Unlike MOBs, they failed to react perhaps due to electronic reasons. The ring strain and the electron donating ether group may be facilitating the bis(spirodienone) to act as an electron-rich diene in cycloaddition reactions. Since both the diene and the dienophile are electron-rich, we also carried out the reaction in the presence of Lewis acids.
such as ZnCl₂ and BF₃·OEt₂. However the reaction did not occur and the starting compounds were recovered along with minor quantity of p-tert-butylcalix[4]arene obtained by the cleavage of the spiro bond facilitated by the Lewis acid.

2.3.1.2 Reactions of bis(bicyclo[2.2.2]octadienone) derivatives

To have a look into the reactivity of the bisadducts, the cycloadduct 19 acquired from the addition of bis(spirodienone) 16 with DMAD was chosen as a representative. As spiro bonds are easily prone to cleavage, our initial attempt was to generate functionalized calixarenes by making use of that. When we treated the cycloadduct 19 with more than two equivalents of scandium triflate (Sc(OTf)₃) in chloroform under ambient condition, it was observed that no reaction ensued. Even higher temperatures did not have any effect. Attempted reaction of the bisadduct with other Lewis acids like ZnCl₂, BF₃·OEt₂ and trifluoroacetic acid were unsuccessful even under drastic conditions. The inertness of the adduct to undergo cleavage in the presence of Lewis acids as compared to the bis(spirodienone) 16 is probably the result that the homolytic cleavage of the spiro bonds in 19 does not result in the aromatization of the enone.

The ester groups of the DMAD adduct of bis(spirodienone) 19 can easily be hydrolysed to the corresponding tetracarboxylic acids. Reaction of 19 with excess KOH in a mixture of 1:1 ethanol-water at 100 °C for 10 h yielded the tetracarboxylic acid in quantitative yield (scheme 2.10).

![Scheme 2.10: Hydrolysis of DMAD adduct](image)

The compound 32 was characterized by spectroscopic analysis. In the IR spectrum the carbonyl absorption appeared as a broad peak at 1710 cm⁻¹.
characteristic of the acid and enone carbonyl groups. It was supported by $^1$H NMR spectrum showing a pattern similar to that of the starting compound but devoid of the methoxy protons. It was further supported by mass spectral analysis showing the molecular ion peak at 894.9. Owing to solubility problem we were not able to record the $^{13}$C NMR spectrum of the compound 32.

2.3.1.3 Cycloaddition reaction with maleimides and maleic anhydride: synthesis of calix[4]bis(bicyclo[2.2.2]octenone) derivatives

Encouraged by the motivating results obtained with triple bonded systems, we extended our study to double bonded systems. We started our investigation by reacting N-phenylmaleimide 33 with 16. The corresponding bisadduct 34 was obtained in 86% yield (scheme 2.11).

In the IR spectrum of 34, the carbonyl peaks were observed as a broad band at 1717 and a small peak at 1779 cm$^{-1}$. In the $^1$H NMR spectrum, the aromatic protons appeared as multiplet ranging from $\delta$ 7.60 to 7.37 and as a broad singlet at $\delta$ 7.12. The olefinic proton $H_a$ resonated as a singlet at $\delta$ 4.83. The singlet at $\delta$ 3.58 was assigned to the ring junction proton $H_b$. The protons $H_c$ and $H_d$ appeared as multiplets at $\delta$ 3.07 and 2.88 respectively. In the $^{13}$C NMR spectrum the cyclohexenone carbonyl resonated at $\delta$ 202.2 whereas the other two carbonyls appeared at $\delta$ 174.7 and 174.5. The spiro carbon furnished a peak at $\delta$ 82.7.

The reaction of the bis(spirodienone) 16 with maleimide 35 was found to occur only under sealed tube conditions in dry toluene. The reaction also furnished the cycloadduct, 36 in excellent yield (scheme 2.12).
Scheme 2.12: Reaction of bis(spirodienone) with maleimide

The structure of 36 was assigned by IR, NMR and mass spectral analyses. The IR spectrum indicated the characteristic absorption of carbonyl groups at 1786 and 1720 cm\(^{-1}\). In the \(^1\)H NMR spectrum, the NH proton resonated as a singlet at \(\delta 9.70\). The aromatic protons appeared as singlets at \(\delta 7.17\) and 7.07 and the olefinic proton \(\text{H}_a\) resonated as a singlet at \(\delta 4.85\) and the broad singlet (merged with one of the doublets) at \(\delta 3.55\) was assigned to the ring junction proton \(\text{H}_b\). Protons \(\text{H}_c\) and \(\text{H}_d\) were observed as distinct doublets at \(\delta 3.15\) (\(J = 8.1\) Hz) and \(\delta 3.04\) (\(J = 7.8\) Hz). Other protons were in agreement with the assigned structure. The signals at \(\delta 202.9\), 180.6 and 179.7 in the \(^{13}\)C NMR spectrum were characteristic of the carbonyl groups. The spiro carbon resonated at \(\delta 82.7\).

Similarly, bis(spirodienone) 16 underwent facile cycloaddition with maleic anhydride 37 affording the bis(bicyclo[2.2.2]octenone) 38 in excellent yield (scheme 2.13).

Scheme 2.13: Reaction of bis(spirodienone) with maleic anhydride

The structure of the product 38 was established by spectroscopic methods. The characteristic carbonyl absorptions were observed at 1784 and
1747 cm$^{-1}$ in the IR spectrum. The $^1$H NMR spectrum was found to be similar to that of product 36.

### 2.3.1.4 Cycloaddition reaction with acrylonitrile, acrolein and methyl acrylate

The reaction was then extended to unsymmetric olefinic systems with electron withdrawing groups. A single regioisomer 40 was obtained in excellent yield in the reaction of bis(spirodienone) 16 with acrylonitrile 39 in anhydrous toluene under reflux (scheme 2.14).

![Scheme 2.14: Cycloaddition reaction of bis(spirodienone) with acrylonitrile](image)

The product 40 was characterized by spectroscopic methods. The IR spectrum showed carbonyl absorption at 1739 cm$^{-1}$. The characteristic C≡N stretching absorption band was observed at 2236 cm$^{-1}$. The regiochemistry of 40 was derived from extensive NMR analysis. In the $^1$H NMR spectrum (figure 2.7), the aromatic protons appeared as singlets at δ 7.08 and 7.01. The olefinic proton H$_a$ appeared as a singlet at δ 4.76 and the ring junction proton H$_b$ as a broad singlet at δ 3.07. A doublet of doublet at δ 2.72 was assigned to the proton H$_e$. The protons H$_d$ and H$_e$ resonated as multiplets at δ 2.05 and 1.75 respectively. The proton connectivity was established by 2D COSY experiment (figure 2.8). $^1$H-$^1$H relayed COSY of 40 showed the through bond connectivities between two different sets of hydrogen atoms. The proton H$_e$, which appeared as a double doublet is connected to both the H$_e$ and H$_d$ protons which resonated as multiplets. The protons H$_d$ and H$_e$ showed correlation with both H$_c$ and the ring junction proton H$_b$. The $^{13}$C NMR spectrum (figure 2.9) displayed the characteristic carbonyl and cyano carbon resonances at δ 204.0 and 108.7. The peak at δ 84.3 was assigned to the spiro carbon. The adduct
obtained was further supported by mass spectral analysis showing the \([M^+1]\) peak at 751.0.

**Figure 2.7**: $^1H$ NMR spectrum of compound 40

**Figure 2.8**: $^1H-^1H$ COSY spectrum of 40
Diels-Alder reaction of bis(spirodieneones)

Figure 2.9. $^{13}$C NMR spectrum of 40

Similar reactivity was observed with acrolein to afford the bis(bicyclo[2.2.2]octenone) derivative 42 in excellent yield (scheme 2.15).

Scheme 2.15: Reaction of bis(spirodiene) with acrolein

The structure of the product 42 was ascertained from spectral data. The IR spectrum showed a broad absorption band at 1730 cm$^{-1}$ due to the ring carbonyl and aldehyde carbonyl moiety. In the $^1$H NMR spectrum, the aldehyde proton appeared as a singlet at $\delta$ 9.47. All other protons were in agreement with the assigned structure. It was further supported by $^{13}$C NMR spectrum, which displayed the aldehyde carbonyl resonance at $\delta$ 201.0. The ring carbonyl and the spiro carbon were visible at $\delta$ 202.4 and 84.3 respectively.

Subsequently, we examined the reaction of bis(spirodieneone) with methyl acrylate, which too yielded the corresponding bisadduct 44 in good yield (scheme 2.16).
Scheme 2.16: Cycloaddition reaction with methyl acrylate

The product 44 was characterized by spectral analysis. The broad absorption at 1738 cm$^{-1}$ in the IR spectrum was characteristic of the two carbonyl groups. In the $^1$H NMR spectrum, the methoxy proton resonated as a singlet at δ 3.79. The other protons resonated in the similar pattern as that of the adduct 40. The $^{13}$C NMR spectrum displayed the ring carbonyl and the ester carbonyl carbons at δ 203.5 and 172.5 respectively. The spiro carbon was visible at δ 83.7. All other signals were in agreement with the assigned structure.

The cycloaddition reaction of bis(spirodienone) with unsymmetric dienophiles can, in principle, result in the formation of two regioisomeric adducts. However, the reaction yielded a single regioisomer. The above discussion discloses the highly selective Diels-Alder reaction of bis(spirodienone) with unsymmetric electron-deficient dienophiles leading to the bis(bicyclo[2.2.2]octenone) derivatives in excellent yields.

In the light of the successful results obtained with symmetric and unsymmetric electron deficient dienophiles we attempted the cycloaddition reaction of bis(spirodienone) with electron-rich dienophiles such as benzyl vinyl ether and ethyl vinyl ether under varied reaction conditions. We also attempted the reaction with styrenes (dicyanostyrene and β-nitrostyrenes) under sealed tube conditions. In all the above cases the reactions were unsuccessful and the bis(spirodienone) was recovered as such. The reason for the failure of the reaction in the former case might be the electronic factors and for the latter case might be the unfavourable interaction among the substrates.
2.3.2 Cycloaddition Reactions with Heterodienophiles

2.3.2.1 Cycloaddition reactions with 1,2,4-triazoline-3,5-diones

In continuation of our efforts to broaden the versatility of calix[4]bis(spirodienones), we also contemplated their Diels-Alder reaction with various heterodienophiles to generate functionalized bicyclo[2.2.2]octenone derivatives. 1,2,4-Triazoline-3,5-diones are very reactive cyclic azadienophiles and they have an intrinsic capability to introduce an N-N moiety into the structure of the cycloadduct. The triazoline diones used as synthons in this section were prepared by the oxidation of the corresponding urazole derivative using tert-butyl hypochlorite.

We commenced our study by reacting the bis(spirodienone) 16 with N-phenyl-1,2,4-triazoline-3,5-dione 45. A facile reaction occurred at ambient conditions leading to the formation of the cycloadduct 46 in quantitative yield (scheme 2.17). After purification by column chromatography essentially to remove the excess dienophile, the product 46 was fully characterized by spectral techniques.

The ring carbonyl and the carbonyl groups of the triazoline part showed strong absorptions at 1712 and 1762 cm\(^{-1}\) respectively in the IR spectrum. The highly symmetrical nature of the cycloadduct was evident from the \(^1\)H NMR spectrum (figure 2.10), which showed well defined proton resonance signals and the salient features are as follows: (a) the aromatic protons were seen as multiplet centered at \(\delta\) 7.45 and as singlets at \(\delta\) 7.20 and 7.10; (b) the olefinic proton \(H_a\) resonated as a singlet at \(\delta\) 5.24; (c) the doublet at \(\delta\) 5.11 \((J = 1.8 \text{ Hz})\)
was assigned to the ring junction proton \( H_b \); (d) the methylene protons appeared as four doublets in a definite pattern and (e) the tert-butyl groups as two distinct singlets at \( \delta 1.33 \) and 1.07.

\[ \text{Figure 2.10: }^1H \text{ NMR spectrum of compound } 46 \]

The \(^{13}\text{C} \) NMR spectrum (figure 2.11) displayed signals at \( \delta 193.4, 154.6 \) and 154.2 corresponding to the enone and dione carbonyls. The \( \text{sp}^2 \) carbons were discernible between \( \delta 152.3 \) and 118.1. The spiro carbon resonated at the characteristic frequency of \( \delta 81.5 \) and the \( \text{sp}^3 \) carbons attached to N-N group resonated at \( \delta 67.8 \) and 60.6. The signals corresponding to the aliphatic carbons appeared in \( \delta 37.1-26.5 \) region. All other signals were in good agreement with the assigned structure.

\[ \text{Figure 2.11: }^{13}\text{C} \text{ NMR spectrum of compound } 46 \]
The molecular ion peak at 996.0 in the mass spectrum also supported the structure. Finally, the proposed structure 46 was confirmed unambiguously by single crystal X-ray analysis (figure 2.12).

Figure 2.12: Single crystal X-ray structure of compound 46

The reaction was found to be general with 1,2,4-triazoline-3,5-diones and the results are summarized in table 2.2. N-Cyclohexyl-1,2,4-triazoline-3,5-dione 47 reacted in a similar manner yielding the cycloadduct 48 in excellent yield, and was characterized by spectroscopic methods. The reaction of bis(spirodieneone) with N-benzyl-1,2,4-triazoline-3,5-dione 49 also furnished the corresponding adduct 50 in quantitative yield. The structure of the product was ascertained on the basis of spectral data. In the $^1$H NMR spectrum, the aromatic protons of the phenyl group appeared as multiplet centered at $\delta$ 7.33 and the analogous protons of the spiroenone part resonated as two singlets at $\delta$ 7.15 and 7.10. The benzylic proton was visible as a distinct singlet at $\delta$ 4.56. All other protons were in agreement with the assigned structure. It was further supported by $^{13}$C NMR spectrum.

Unlike 48 and 50, the products 52, 54 and 56 were only moderately soluble in solvents like CHCl$_3$, CH$_2$Cl$_2$, etc. This created trouble for their $^{13}$C NMR analysis and the problem was solved by adding a drop of TFA to the deuterated CDC$_3$ solution which helped in solubilizing the adducts. This was done after confirming that there was no reaction between TFA and the triazoline derived adducts. The above results revealed that in all the cases the
reaction occurred under mild conditions and the products were isolated in excellent yields.

**Table 2.2: Cycloaddition reaction with various triazoline diones**

<table>
<thead>
<tr>
<th>Entry</th>
<th>R</th>
<th>Time (t h)</th>
<th>Product</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-Cy(47)</td>
<td>10</td>
<td>48</td>
<td>86</td>
</tr>
<tr>
<td>2</td>
<td>-CH₂Ph (49)</td>
<td>8</td>
<td>50</td>
<td>99</td>
</tr>
<tr>
<td>3</td>
<td>-CH₂Ph-OMe (51)</td>
<td>8</td>
<td>52</td>
<td>98</td>
</tr>
<tr>
<td>4</td>
<td>-CH₂Ph-Me (53)</td>
<td>10</td>
<td>54</td>
<td>98</td>
</tr>
<tr>
<td>5</td>
<td>-CH₂Ph-Cl (55)</td>
<td>10</td>
<td>56</td>
<td>90</td>
</tr>
</tbody>
</table>

*Reaction conditions: toluene, Ar, room temperature*

### 2.3.2.2 Cycloaddition reactions with N,N-dialkyl azodicarboxylates

It was observed that the cycloaddition of 16 with diethyl azodicarboxylate\(^\text{20-22}\) required more stringent conditions and the cycloadduct 58 was obtained by treating 16 with 57 in anhydrous toluene under reflux for 7 h (scheme 2.18).

**Scheme 2.18: Reaction of 16 with diethyl azodicarboxylate**

The IR spectrum of the compound 58 displayed strong carbonyl absorptions at 1756, 1737 and 1703 cm\(^{-1}\) corresponding to the ester carbonyl
groups and the ring carbonyls respectively. In the $^1$H NMR spectrum, the aromatic protons resonated as two singlets at $\delta$ 7.12 and 6.98. The singlet which appeared at $\delta$ 5.43 was assigned to the olefinic proton, H$_a$. The ring junction proton, H$_b$ appeared as a singlet at $\delta$ 5.20. The -OCH$_2$ protons of the ester group resonated as a multiplet at $\delta$ 4.19. The CH$_3$ protons were observed as a multiplet ranging from $\delta$ 1.26-1.15. All other proton signals were in good concurrence with the proposed structure. The ester carbonyl and the ring carbonyls displayed $^{13}$C resonance signals at $\delta$ 196.9, 159.1 and 154.9 respectively. The signal at $\delta$ 84.3 was assigned to the spiro carbon.

With diisopropyl azodicarboxylate 59 the reaction occurred in an analogous way affording the product 60 in quantitative yield (scheme 2.19). The structure was established on the basis of spectral data.

**Scheme 2.19: Reaction of 16 with diisopropyl azodicarboxylate**

As an extension, we allowed the bis(spirodienone) to react with di-tert-butyl azodicarboxylate under the above mentioned reaction conditions. However the reaction was not successful even under sealed tube conditions and the starting compound was recovered. The reason behind the failure of the reaction might be attributed to the steric hindrance offered by the bulky tert-butyl groups of the azo compound.

Evaluation of our results disclosed that the reaction of bis(spirodienone) with heterodienophiles were found to occur under mild conditions and in excellent yields compared to carbodienophiles. This can be explained on the basis of molecular orbital theory which states, the energy of the LUMO of dienophile can be reduced by having an oxygen or nitrogen atom in the $\pi$ bond.
Because $p$-orbitals on these atoms lie at a much lower energy than those on carbon, the $\pi$ molecular orbital that they make will inevitably have low-energy HOMOs and LUMOs. Hence they can act as efficient dienophiles in Diels-Alder reactions.

The above discussion furnishes a clear picture on the role of bis(spirodienone) as an efficient diene in its cycloaddition reactions with carbodienophiles and heterodienophiles. Since spirodienone resembles structurally MOBs, they may also act as a dienophile in cycloaddition reactions. This instigated us to look into its role as a dienophile in Diels-Alder reactions. We attempted the reaction of bis(spirodienone) with 2-methyl furan in toluene under sealed tube condition for 24 h. Though the reaction was allowed to run for a longer time, it did not yield any product and the starting compound was recovered quantitatively. The inertness of the spirodienone to furan may be due to its decreased reactivity arising from the aromatic stability of furan and the poor electrophilic nature of the spirodienone part.

Similar failures were recorded in attempted reactions of bis(spirodienone) with 1,3-butadienes such as 2,3-dimethoxy butadiene and 2,3-dimethyl butadiene even under stringent reaction conditions, perhaps due to electronic reasons and lack of favourable secondary orbital interaction.

2.4 Conclusion

In conclusion, we have successfully employed the Diels-Alder chemistry to enable synthetic transformations of calix[4]bis(spirodienone) via spirodienone route. In the first part of the discussion, we have shown that the bis(spirodienones) can act as an efficient diene with a wide range of carbodienophiles. The reactions led to the formation of highly regio- and stereoselective bis(bicyclo[2.2.2]octenone) derivatives in good to excellent yields. All the compounds were thoroughly characterized on the basis of spectral data.

Further, we uncovered the cycloaddition reaction of bis(spirodienone) with a number of heterodienophiles. The reaction was found to occur under
mild conditions and afforded the highly functionalized macrocycles in comparatively high yield.

The present chapter also unravelled a comparison between the reactivity of bis(spirodienone) and masked ortho-benzoquinones (MOBs). Calix[4]bis(spirodienones) were found to act as electron-rich dienes in cycloaddition reactions. The mode of addition of dienophiles across the diene was found to be similar to that of MOBs. Unlike MOBs, they failed to react with electron-rich dienophiles.

The adducts obtained (bisbicyclo[2.2.2]octenone, triazoline dione and hydrazine derivatives) can be potential candidates for further functionalization and it is conceivable that the present strategy may open up possibilities for the construction of new macrocycles from the calix[4]arene skeleton.

2.5 Experimental Details

All reactions were conducted in oven-dried glasswares under an atmosphere of argon with magnetic stirring unless otherwise noted. Solvents used for experiments were distilled and dried according to procedures given in standard manuals. Melting points were recorded on a Büchi melting point apparatus and are uncorrected. NMR spectra were recorded at 300 (1H) and 75 (13C) MHz respectively on a Bruker Avance DPX-300 MHz NMR spectrometer. Chemical shifts are reported in δ (ppm) relative to TMS (1H) and CDCl₃ (13C) as the internal standards. Coupling constants (J) are reported in Hertz (Hz). IR spectra were recorded on Bomem MB Series FT-IR spectrometer; absorbances are reported in cm⁻¹. Mass spectra were recorded under FAB/LRMS at 5000 resolution using JEOL JMS 600H mass spectrometer. Elemental analyses were done using Perkin Elmer-2400 CHNS analyzer. Analytical thin layer chromatography was performed on glass plates coated with silica gel containing calcium sulfate as the binder; visualization was effected with a UV lamp and/or by developing in iodine. Gravity column was performed using 100-200 mesh silica gel and mixtures of hexane-ethyl acetate were used for elution. The reagents used were purchased from Aldrich.
Chemical Co. and were used without further purification. 1,2,4-Triazoline-3,5-diones were prepared by reported procedure. Recrystallisation was done by slow evaporation method from dichloromethane-acetonitrile mixture at room temperature.

**Procedure for the preparation of calix[4]bis(spirodienones)** 16 and 17

To a solution of calix[4]arene (2 g, 3.08 mmol) in 80 mL of CH$_2$Cl$_2$ was dropped with stirring phenyltrimethylammonium tribromide (2.3 g, 6.14 mmol) dissolved in 27 mL of CH$_2$Cl$_2$ during 1 h, and then 100 g of a 28% aqueous NaOH solution was dropped during 30 min. The solution was refluxed under stirring for 4 h. The solution was cooled to rt, 10 mL of CH$_2$Cl$_2$ and 10 mL of water were added, and after phase separation the organic phase was washed with brine, water and then dried over anhydrous Na$_2$SO$_4$. After the organic solvent was evaporated, the residue was chromatographed (silica, eluent: chloroform) and the compounds isolated were recrystallized from CH$_2$Cl$_2$-CH$_3$CN mixture yielding 500 mg of 16 (25%) and 150 mg of 17 (8%).

7H,11H,18H,22H-7,10:18,21-Dietheno-4,6:6,10:15,17:17,21-tetramethano dibenzo-[b,k]-[1,10]dioxacyclooctadecin-8,9,19,20-tetracarboxylic acid-2,13,24,28-tetakis(1,1-dimethylethyl)-26,29-dioxo-8,9,19,20-tetramethyl ester [19]

Calix[4]bis(spirodienone) 16 (50 mg, 0.08 mmol) was dissolved in dry toluene (8 mL) under inert atmosphere. Dimethyl acetylenedicarboxylate 18 (23 mg, 0.16 mmol) was added to it and stirred at rt for 12 h. The solvent was removed under vacuum and the residue subjected to silica gel column chromatography to remove the excess dienophile using 85:15 hexane-ethyl acetate solvent mixture to afford 19 (70 mg, 99%) as a white crystalline solid. m.p. decomposed > 300 °C.
Diels-Alder reaction of bis(spirodieneones)

IR (KBr) $v_{\text{max}}$: 2957, 2935, 1746, 1710, 1613, 1480, 1363, 1327, 1261, 1137, 1091, 1058, 983, 937, 895, 829 cm$^{-1}$.

$^1$H NMR: $\delta$ 7.06 (s, 2H), 6.89 (s, 2H), 4.82 (d, $J = 2.1$ Hz, 2H), 4.35 (d, $J = 2.1$ Hz, 2H) 4.09 (d, $J = 14.4$ Hz, 2H), 3.87 (s, 6H), 3.79 (s, 6H), 3.31 (d, $J = 15.6$ Hz, 2H), 3.00 (d, $J = 15.6$ Hz, 2H), 2.55 (d, $J = 14.5$ Hz, 2H), 1.30 (s, 18H), 0.98 (s, 18H).

$^{13}$C NMR: $\delta$ 192.7, 166.0, 163.0, 154.6, 153.5, 150.8, 144.2, 135.5, 127.6, 125.5, 120.3, 118.9, 118.4, 77.2, 59.5, 52.5, 52.4, 47.7, 38.8, 34.5, 34.3, 31.7, 27.7, 27.2.

MS (FAB, [M$^+$+H$^-$]): Calcd for C$_{56}$H$_{64}$O$_{12}$: 929.44; Found: 929.73.

Elemental Analysis calculated for C$_{56}$H$_{64}$O$_{12}$: C, 72.39; H, 6.94; Found: C, 72.04; H, 7.20.

7H,11H,18H,22H-7,10:18,21-Dietheno-4,6:6,10:15,17:17,21-tetramethano dibenzo-[b,k][1,10]dioxacyclooctadecin-8,9,19,20-tetracarboxylic acid-2,13,24,28-tetrakis(1,1-dimethylethyl)-26,29-dioxo-8,9,19,20-tetra-tert-butyl ester [21]

A mixture of 16 (50 mg, 0.08 mmol) and di-tert-butyl acetylenedicarboxylate 20 (37 mg, 0.16 mmol) in dry toluene (5 mL) was refluxed under argon atmosphere for 10 h. Then, the volatiles were removed under reduced pressure and the residue was subjected to purification by column chromatography on silica gel using 97:3 hexane-ethyl acetate mixture to obtain the adduct 21 (98 mg, 99%) as a white crystalline solid. m.p. decomposed $>$ 298 °C.

IR (KBr) $v_{\text{max}}$: 2957, 2929, 1744, 1701, 1484, 1393, 1367, 1328, 1272, 1258, 1164, 1138, 1055, 944, 896, 787 cm$^{-1}$. 

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**Note:** The provided text appears to be a chemical synthesis and characterization report. It includes spectral data (IR, NMR, MS), and an elemental analysis. The text describes the synthesis of a complex organic compound, detailing the reagents used, the reaction conditions, and the characterization of the product. The use of units such as cm$^{-1}$ for IR frequencies, and ppm for NMR chemical shifts, along with descriptions of melting points and yield percentages, indicates a thorough and methodical approach to organic synthesis and analysis. The text is likely sourced from a scientific journal or a research paper focused on organic chemistry. The provided text is representative of the type of information found in such sources, relating to the synthesis and characterization of a specific compound through a Diels-Alder reaction involving bis(spirodieneones).
$^1$H NMR: δ 7.07 (s, 2H), 6.86 (s, 2H), 4.73 (d, $J = 2.1$ Hz, 2H), 4.18 (d, $J = 2.1$ Hz, 2H), 4.07 (d, $J = 14.1$ Hz, 2H), 3.26 (d, $J = 15.6$ Hz, 2H), 3.04 (d, $J = 15.6$ Hz, 2H), 2.67 (d, $J = 14.4$ Hz, 2H), 1.56 (s, 18H), 1.50 (s, 18H), 1.30 (s, 18H), 0.97 (s, 18H).

$^{13}$C NMR: δ 192.3, 164.6, 162.6, 155.2, 153.1, 149.0, 144.0, 136.7, 127.5, 126.1, 120.2, 119.8, 118.9, 116.5, 82.9, 82.1, 77.4, 59.5, 48.2, 38.7, 34.4, 34.3, 31.9, 28.4, 28.2, 27.8, 27.7.

MS (FAB, [M$^+$+H$^+$]): Calcd for $\text{C}_{68}\text{H}_{86}\text{O}_{12}$: 1097.63; Found: 1097.95.

7H,11H,18H,22H-7,10:18,21-Dietheno-4,6,10:15,17:17,21-tetramethano
dibenzo-[b,k] [1,10] dioxacyclooctadecin-9,20-dicarboxylic acid-2,13,24,28-
tetrakis(1,1-dimethylethyl)-26,29-dioxo-9,20-dimethyl ester [23]

To a solution of 16 (50 mg, 0.08 mmol) in anhydrous toluene (5 mL) was added methyl propiolate 22 (14 mg, 0.16 mmol). Refluxed the reaction mixture for 12 h till completion as indicated by TLC. From the crude, the product 23 was obtained as a white crystalline solid (64 mg, 94%) after chromatographic separation using 90:10 hexane-ethyl acetate mixture. m.p. decomposed >300 °C.

IR (KBr) $v_{\text{max}}$: 2957, 2902, 1742, 1719, 1480, 1363, 1308, 1235, 1203, 1100, 1059, 942, 902, 759 cm$^{-1}$.

$^1$H NMR: δ 7.22 (d, $J = 6.5$ Hz, 2H), 7.01 (s, 2H), 6.94 (s, 2H), 4.92 (d, $J = 2.2$ Hz, 2H), 4.28 (d, $J = 15.2$ Hz, 2H), 3.84 (dd, $J_1 = 2.3$ Hz, $J_2 = 6.5$ Hz, 2H ), 3.77 (s, 6H), 3.38 (d, $J = 15.5$ Hz, 2H), 3.18 (d, $J = 15.3$ Hz, 2H), 2.80
Diels-Alder reaction of bis(spirodienones)

(d, J = 15.6 Hz, 2H), 1.30 (s, 18H), 0.96 (s, 18H).

$^{13}$C NMR: δ 193.3, 164.3, 154.6, 151.8, 144.8, 143.5, 141.1, 127.7, 125.4, 120.2, 119.7, 118.9, 116.8, 78.5, 58.0, 51.6, 47.6, 34.1, 33.9, 31.7, 30.7, 29.4, 28.8, 27.4.

MS (FAB, M$^+$): Calcd for C$_{52}$H$_{60}$O$_8$: 812.43; Found: 812.11.

7H,11H,18H,22H-7,10:18,21-Dietheno-4,6:6,10:15,17:17,21-tetramethano dibenzo-[b,k] [1,10] dioxcyclooctadecin-9,20-dicarboxylic acid-2,13,24,28-tetrakis(1,1-dimethylethyl)-26,29-dioxo-8,19-diphenyl-9,20-dimethyl ester [25]

Methyl phenyl propiolate 24 (26 mg, 0.16 mmol) was added to a solution of 16 (50 mg, 0.08 mmol) in 5 mL anhydrous toluene and the reaction mixture was refluxed for 12 h. The residue obtained after the removal of the solvent was purified by column chromatography using 98:2 hexane-ethyl acetate mixture as eluent to afford the product 25 as a white crystalline solid (55 mg, 88%). m.p. decomposed > 295 °C.

IR (KBr) $\nu_{max}$: 2955, 2868, 1738, 1700, 1483, 1437, 1363, 1331, 1247, 1204, 1139, 942, 895, 869, 835, 767, 704 cm$^{-1}$.

$^1$H NMR: δ 7.35-7.25 (m, 9H), 7.05 (s, 3H), 6.67 (s, 2H), 4.92 (s, 2H), 4.41 (d, J = 2.1 Hz, 2H), 3.80 (d, J = 14.7 Hz, 2H), 3.50 (s, 6H), 3.41 (d, J = 15.6 Hz, 2H), 3.14 (d, J = 15.6 Hz, 2H), 2.24 (d, J = 15.0 Hz, 2H), 1.28 (s, 18H), 1.01 (s, 18H).

$^{13}$C NMR: δ 195.1, 165.0, 159.5, 155.0, 153.6, 143.7, 136.2, 134.7, 127.9, 127.6, 127.2, 125.5, 119.9, 118.9, 78.1, 62.2, 51.7,
48.3, 38.9, 34.4, 34.2, 31.2, 29.4, 27.6.

**MS** (FAB, [M⁺+H]): Calcd for C₆₄H₆₈O₆: 965.49; Found: 965.89.

**Bis(bicyclo[2.2.2]octadienones) [27] and [28]**

Calix[4]bis(spirodieneone) 16 (50 mg, 0.08 mmol) was dissolved in dry toluene (5 mL) under inert atmosphere. Ethyl 2-butyroate 26 (18.2 mg, 0.16 mmol) was added to it and refluxed for 18 h. The solvent was removed under vacuum and the residue subjected to silica gel column chromatography (95:5 hexane-ethyl acetate) to furnish the products 27 (20 mg, 33%) and 28 (26 mg, 33%) as a mixture of two regioisomers in 1:1 ratio. m.p. decomposed > 295 °C.

7H,11H,18H,22H-7,10:18,21-Dietheno-4,6:6,10:15,17:17,21-tetramethanodibenzo-[b,k] [1,10] dioxacyclooctadecin-9,20-dicarboxylic acid-2,13,24,28-tetrakis(1,1-dimethylethyl)-26,29-dioxo-8,19-dimethyl-9,20-diethyl ester [27]

**IR (KBr)** $v_{max}$: 2957, 2910, 2869, 1739, 1697, 1483, 1465, 1365, 1315, 1230, 1203, 1055, 898, 836 cm⁻¹.

**¹H NMR:** δ 7.05 (s, 2H), 6.89 (s, 2H), 4.76 (s, 2H), 4.27 (m, 6H), 4.06 (d, $J = 14.5$ Hz, 2H), 3.22 (d, $J = 15.4$ Hz, 2H), 3.08 (d, $J = 16.1$ Hz, 2H), 2.80 (d, $J = 14.6$ Hz, 2H), 2.20 (s, 6H), 1.31 (s, 18H).1.30 (m, 6H), 0.95 (s, 18H).

**¹³C NMR:** δ 194.7, 165.5, 158.1, 155.5, 152.6, 144.0, 132.6, 127.7, 126.3, 120.3, 118.8, 784, 62.7, 60.9, 48.4, 39.0, 34.4, 32.1, 28.6, 27.8, 15.7, 14.7.

**MS** (FAB, [M⁺+H]): Calcd for C₅₆H₆₈O₆: 869.49; Found: 869.25.
Diels-Alder reaction of bis(spirodienones)

7H,11H,18H,22H-7,10:18,21-Dietheno-4,6:6,10:15,17:17,21-tetramethano
dibenzo-[b,k] [1,10] dioxacyclooctadecin-8,19-dicarboxylic acid-2,13,24,28-
tetrakis(1,1-dimethylethyl)-26,29-dioxo-9,20-dimethyl-8,19-diethyl ester [28]

IR (KBr) $\nu_{\text{max}}$: 2957, 2910, 2871, 1742, 1700, 1483, 1455, 1387, 1340, 1315, 1230, 1055, 956, 898, 836 cm$^{-1}$.

$^1$H NMR: $\delta$ 7.03 (s, 2H), 6.86 (s, 2H), 4.84 (d, $J = 2.1$ Hz, 2H), 4.28 (m, 6H), 3.59 (s, 2H), 3.34 (d, $J = 15.7$ Hz, 2H), 2.94 (d, $J = 15.4$ Hz, 2H), 2.60 (d, $J = 14.9$ Hz, 2H), 2.10 (s, 6H), 1.33 (s, 18H), 1.30 (m, 6H), 0.96 (s, 18H).

$^{13}$C NMR: $\delta$ 195.0, 165.8, 158.5, 156.4, 151.6, 143.9, 132.8, 128.0, 126.5, 120.6, 118.7, 78.7, 62.9, 61.0, 48.5, 39.2, 34.7, 32.9, 28.9, 27.6, 16.1, 14.9.

MS (FAB, [M$^+$+H]): Calcd for C$_{56}$H$_{68}$O$_8$: 869.49; Found: 869.25.

7H,11H,18H,22H-7,10:18,21-Dietheno-4,6:6,10:15,17:17,21-tetramethano
dibenzo-[b,k] [1,10] dioxacyclooctadecin-8,19-bis(2,2-dimethylpropionyl)-9,20-
dicarboxylic acid-2,13,24,28-tetrakis(1,1-dimethylethyl)-26,29-dioxo-9,20-
dimethyl ester [30]

7H,11H,18H,22H-7,10:18,21-Dietheno-4,6:6,10:15,17:17,21-tetramethano
dibenzo-[b,k][1,10]dioxacyclooctadecin-8,19-dicarboxylic acid-9,20-bis(2,2-
dimethyl-propionyl)-2,13,24,28-tetrakis(1,1-dimethylethyl)-26,29-dioxo-8,19-
dimethyl ester [31]

A mixture of 16 (50 mg, 0.08 mmol) and methyl 5,5-dimethyl-4-oxo-2-
hexynoate 29 (27 mg, 0.16 mmol) in dry toluene (5 mL) was stirred at 110 $^\circ$C
for 18 h. The solvent was evaporated and the residue was chromatographed on
silica gel (95:5 hexane-ethyl acetate) to furnish the bisadducts 30 and 31 (74
mg, 98%) as an inseparable mixture of regioisomers in the ratio 1:1. m.p. decomposed > 302 °C.

**IR (KBr) v<sub>max</sub>:** 2957, 2912, 2780, 1742, 1716, 1689, 1483, 1436, 1394, 1364, 1263, 1152, 1103, 995, 943, 895, 883 cm<sup>-1</sup>.

**<sup>1</sup>H NMR:** δ 7.08 (s, 4H), 6.90 (m, 4H), 4.94 (m, 4H), 4.37 (s, 2H), 4.20 (d, J = 14.7 Hz, 2H), 3.91 (d, J = 14.4 Hz, 2H), 3.82 (s, 2H), 3.76 (s, 12H), 3.34 (bs, 6H), 3.13 (m, 2H), 2.97 (m, 2H), 2.54 (d, J = 13.8 Hz, 2H), 1.30 (m, 36H), 1.20 (s, 18H), 1.10 (s, 18H), 1.04 (bs, 18H), 0.95 (s, 18H).

**<sup>13</sup>C NMR:** δ 213.0, 211.0, 193.8, 192.6, 192.3, 164.5, 164.0, 157.0, 155.6, 155.2, 154.9, 154.8, 154.6, 154.5, 153.8, 150.8, 150.7, 144.5, 144.4, 144.2, 144.1, 136.3, 136.2, 135.0, 134.8, 128.0, 127.8, 127.6, 126.5, 126.3, 125.6, 125.3, 121.3, 120.4, 120.3, 120.2, 120.0, 119.6, 119.3, 78.3, 78.2, 61.5, 61.4, 57.7, 57.6, 52.6, 52.3, 51.0, 48.3, 44.8, 44.3, 39.3, 39.1, 34.5, 34.4, 31.9, 28.8, 27.7, 27.5, 27.3.

**MS (FAB, [M<sup>+</sup>+Na]):** Calcd for C<sub>62</sub>H<sub>76</sub>O<sub>10</sub>: 1003.54; Found: 1003.58.

7H,11H,18H,22H-7,10:18,21-Dietheno-4,6:6,10:15,17:17,21-tetramethano dibenzo-[b,k]-[1,10]dioxacyclooctadecin-8,9,19,20-tetracarboxylic acid-2,13,24,28-tetrakis(1,1-dimethylethyl)-26,29-dioxo-8,9,19,20-tetramethyl ester (19) on hydrolysis to yield [32]

To a solution of the DMAD adduct 19 (50 mg, 0.05 mmol) in 10 mL ethanol-water (1:1) mixture, excess KOH was added and the solution refluxed
for 10 h. The reaction mixture was cooled to ice temperature and con. HCl was added to it. The tetracarboxylic acid got precipitated as white solid, which was washed with water and dried under vacuum to afford 32 (47 mg, 99%) as a white crystalline solid.

IR (KBr) \( \nu_{\text{max}} \): 2957, 2815, 1710 (broad), 1500, 1485, 1357, 1256, 1055, 1012, 1301, 890, 835 cm\(^{-1}\).

\(^1\)H NMR (CDCl\(_3\)+CF\(_3\)COOH): \( \delta \) 7.17 (s, 2H), 6.98 (s, 2H), 4.93 (d, \( J = 1.9 \) Hz, 2H), 4.48 (d, \( J = 1.8 \) Hz, 2H), 4.26 (d, \( J = 14.3 \) Hz, 2H), 3.41 (d, \( J = 15.6 \) Hz, 2H), 3.10 (d, \( J = 15.8 \) Hz, 2H), 2.70 (d, \( J = 14.5 \) Hz, 2H), 1.34 (s, 18H), 1.02 (s, 18H)

MS (FAB, [M\(^{+}\)+Na]): Calcd for C\(_{52}\)H\(_{56}\)O\(_{12}\): 895.38; Found 894.92.

2,8,13,19-Tetrakis(1,1-dimethylethyl)-11H,22H-4,6:6,10:15,17:17,21-tetramethanodi-benza[b,k][1,10]dioxacyclooctadecin-23,25-dione (16) with N-phenylmaleimide (33) to yield [34]

Calix[4]bis(spirodieneone) 16 (50 mg, 0.08 mmol) was dissolved in dry toluene (8 mL) under inert atmosphere. N-Phenylmaleimide 33 (28 mg, 0.16 mmol) was added to it and stirred at rt for 18 h. The solvent was removed under vacuum and the residue subjected to silica gel column chromatography using 85:15 hexane-ethyl acetate solvent mixture affording 34 as a white solid (66 mg, 86\%). m.p. decomposed > 275 °C.

IR (KBr) \( \nu_{\text{max}} \): 2957, 2903, 2868, 1717 (broad), 1498, 1485, 1377, 1201, 1187, 1107, 958, 901 cm\(^{-1}\).

\(^1\)H NMR: \( \delta \) 7.60 – 7.37 (m, 6H), 7.12 (bs, 8H), 4.83 (s, 2H), 4.02 (d, \( J = 14.1 \) Hz, 2H), 3.58 (s,
Calix[4]bis(spirodienone) (16) with maleimide (35) to yield [36]

To a mixture of 16 (50 mg, 0.08 mmol) and maleimide 35 (16 mg, 0.16 mmol), 5 mL dry toluene was added and the reaction mixture was refluxed under argon atmosphere for 4 h. The solvent was stripped off under reduced pressure and the product was isolated by precipitation from a mixture of chloroform and acetonitrile. The cycloadduct 36 was obtained in the pure form as white solid (65 mg, 98%). m.p. decomposed > 267 °C.

**IR (KBr) V\text{max}**: 2954, 2859, 1786, 1720, 1485, 1415, 1346, 1312, 1288, 1250, 1195, 892, 786 cm\(^{-1}\).

**\(^1\text{H NMR}**: \(\delta\) 9.70 (s, 2H), 7.17 (s, 2H), 7.07 (s, 2H), 4.85 (s, 2H), 4.01 (d, \(J = 14.7\) Hz, 2H), 3.55 (bs, 2H), 3.50 (d, \(J = 15.6\) Hz, 2H), 3.30 (d, \(J = 14.4\) Hz, 2H ), 3.25 (d, \(J = 15.9\) Hz, 2H), 3.15 (d, \(J = 8.1\) Hz, 2H), 3.04 (d, \(J = 7.8\) Hz, 2H), 1.32 (s, 18H), 0.93 (s, 18H).

**\(^{13}\text{C NMR}**: \(\delta\) 202.9, 180.6, 179.7, 150.5, 145.8, 128.1, 124.3, 119.7, 118.7, 117.3, 82.7, 51.1, 49.0, 45.4, 42.5, 37.2, 34.4, 31.6, 29.9, 27.7.
Diels-Alder reaction of bis(spirodieneones)


Calix[4]bis(spirodieneone) (16) with maleic anhydride (37) to yield [38]

Maleic anhydride 37 (16 mg, 0.16 mmol) was added to a solution of 16 (50 mg, 0.08 mmol) in dry toluene (5 mL). The reaction mixture was refluxed for 4 h. The residue obtained after the removal of the solvent was purified by precipitation from a mixture of chlorofrom-acetonitrile to furnish the product 38 as white solid (64 mg, 98%). m.p. decomposed > 277 °C.

IR (KBr) v max: 2968, 2789, 1784, 1747, 1485, 1478, 1395, 1365, 1327, 1236, 1106, 933, 890 cm⁻¹.

¹H NMR: δ 7.18 (s, 2H), 7.12 (s, 2H), 4.90 (s, 2H), 4.03 (d, J = 14.7 Hz, 2H), 3.61 (s, 2H), 3.49 (d, J = 15.3 Hz, 2H), 3.31 (m, 4H), 3.21 (m, 4H), 1.33 (s, 18H), 0.96 (s, 18H).

¹³C NMR: δ 199.8, 171.4, 154.5, 151.7, 146.7, 129.7, 125.6, 121.0, 119.7, 117.2, 112.1, 82.9, 51.3, 49.4, 46.0, 42.4, 37.4, 34.6, 34.5, 28.0.

MS (FAB, [M⁺+H]): Calcd for C₅₂H₅₆O₁₀: 841.39; found: 841.34.

7H,11H,18H,22H-7,10:18,21-Diethano-4,6:6,10:15,17:17,21-tetramethano dibenzo-[b,k][1,10]dioxacyclooctadecin-2,13,24,28-tetrakis(1,1-dimethylethyl)-26,29-dixo-9,20-dicarbonitrile [40]

A solution of 16 (50 mg, 0.08 mmol) and acrylonitrile 39 (8.6 mg, 0.16 mmol) in 2 mL dry toluene in a sealed tube was heated at 110 °C under reduced pressure for 8 h. The solvent was removed under vacuum and the residue on silica gel column chromatography using 90:10 hexane-ethyl acetate mixture afforded 40 as a white crystalline solid (50 mg, 86%). m.p. decomposed> 270 °C.
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IR (KBr) $\nu_{\text{max}}$: 2954, 2894, 2236, 1739, 1483, 1363, 1356, 1282, 1254, 1203, 1143, 1098, 1047, 937 cm$^{-1}$.

$^1$H NMR: $\delta$ 7.08 (s, 2H), 7.01 (s, 2H), 4.76 (s, 2H), 4.05 (d, $J = 14.5$ Hz, 2H), 3.40 (d, $J = 15.3$ Hz, 2H), 3.07 (bs, 2H), 3.05 (d, $J = 14.9$ Hz, 2H), 2.72 (dd, $J_1 = 2.9$ Hz, $J_2 = 9.4$ Hz, 2H), 2.45 (d, $J = 14.6$ Hz, 2H), 2.05 (m, 2H), 1.75 (m, 2H), 1.31 (s, 18H), 1.01 (s, 18H).

$^{13}$C NMR: $\delta$ 204.4, 154.5, 145.7, 127.7, 125.0, 120.7, 120.0, 119.3, 117.3, 108.7, 84.3, 51.7, 42.8, 37.4, 37.0, 35.1, 31.5, 30.6, 27.3.

MS (FAB, [M$^+$+H]): Calcd for C$_{50}$H$_{88}$N$_2$O$_4$: 751.44; Found: 751.04.

7H,11H,18H,22H-7,10:18,21-Diethano-4,6:6,10:15,17:17',21-tetramethano
dibenzo-[b,k][1,10] dioxacyclooctadecin-2,13,24,28-tetrakis(1,1-dimethylethyl)-
26,29-dioxo-9,20-dicarbaldehyde [42]

16 (50 mg, 0.08 mmol) and acrolein 41 (9 mg, 0.16 mmol) were taken in
a sealed tube. To that 2 mL dry toluene was added and after applying vacuum,
the reaction was carried out at 110 °C for 10 h. The solvent was removed under
reduced pressure and the residue was purified by silica column chromatography
using 90:10 hexane-ethyl acetate solvent mixture to afford 42 as a white
crystalline solid (51 mg, 86%). m.p. decomposed $>268$ °C.

IR (KBr) $\nu_{\text{max}}$: 2953, 2906, 2727, 1730
(broad), 1483, 1456, 1436, 1362, 1250, 1205, 939 cm$^{-1}$.

$^1$H NMR: $\delta$ 9.47 (s, 2H), 7.08 (s, 2H), 6.84 (s, 2H), 4.72 (d, $J = 1.5$ Hz, 2H), 4.16 (d, $J = 14.7$ Hz, 2H), 3.50 (d, $J = 15.3$ Hz, 2H), 3.10
Diels-Alder reaction of bis(spirodienones) (d, J = 15.6 Hz, 2H), 3.08 (s, 2H), 2.46 (d, J = 14.7 Hz, 2H), 2.44 (m, 2H), 1.89 (bs, 4H), 1.30 (s, 18H), 0.98 (s, 18H).

\[^1^3\text{C NMR: } \delta 202.4, 201.0, 154.4, 152.1, 143.8, 126.3, 124.9, 120.0, 119.5, 116.4, 84.3, 55.2, 53.0, 51.5, 42.6, 34.5, 34.1, 31.7, 29.0, 27.4, 23.9.\]

\[\text{MS (FAB, } [\text{M}^+ \text{+H}]): \text{ Calcd for C}_{50}\text{H}_{60}\text{O}_6: 757.44; \text{ Found: 757.27.}\]

7H,11H,18H,22H-7,10:18,21-Diethano-4,6:6,10:15,17:17,21-tetramethano dibenzo-[b,k][1,10]dioxacyclooctadecin-9,20-dicarboxylic acid-2,13,24,28-tetrakis(1,1-dimethylethyl)-26,29-dioxo-9,20-dimethyl ester [44]

16 (50 mg, 0.08 mmol) and methyl acrylate 43 (14 mg, 0.16 mmol) were taken in a sealed tube. To that 2 mL dry toluene was added and after applying vacuum, the reaction was carried out at 110 °C for 12 h. The solvent was removed under reduced pressure and the residue was purified by silica column chromatography using 95:5 hexane-ethyl acetate solvent mixture to afford 44 as white crystalline solid (51 mg, 80%). m.p. decomposed > 283 °C.

\[\text{IR (KBr) } v_{\text{max}}: 2955, 2895, 2784, 1738 \text{ (broad), 1481, 1362, 1258, 1200, 1171, 1049, 935 cm}^{-1}.\]

\[\text{IH NMR: } \delta 7.09 (s, 2H), 6.79 (s, 2H), 4.63 (s, 2H), 3.97 (d, J = 14.6 Hz, 2H), 3.79 (s, 6H), 3.46 (d, J = 15.5 Hz, 2H), 3.11 (d, J = 15.6 Hz, 2H), 3.05 (bs, 2H), 2.74 (dd, J_1 = 3.9 Hz, J_2 = 9.7 Hz, 2H), 2.40 (d, J = 14.7 Hz, 2H), 2.01 \text{ (uneven t, } J_1 = 12.6 \text{ Hz, } J_2 = 11.2 \text{ Hz, 2H), 1.71 (m, 2H), 1.30 (s, 18H), 0.97 (s, 18H).}\]

\[\text{13C NMR: } \delta 203.5, 172.5, 154.7, 149.6, 143.2, 126.6, 124.5, 120.3, 119.3, 116.1, 83.7, 52.0,\]
51.3, 48.0, 42.4, 36.9, 34.3, 31.6, 28.6, 27.3.
MS (FAB, M⁺): Calcd for C₅₂H₆₄O₈: 816.46; Found: 816.48.

Typical experimental procedure for the preparation of N-phenyl-1,2,4-triazoline-3,5-dione (45) starting from phenyl isocyanate

To a solution of methylcarbazate (0.70 g, 0.01 mol) in 15 mL of dry THF was added phenyl isocyanate (1 g, 0.01 mol) and the reaction mixture stirred under nitrogen atmosphere for 16 h at room temperature. After the removal of the solvent under reduced pressure, the crude white solid was filtered and washed with dichloromethane. The hydrazide was obtained as a white crystalline solid (1.6 g, 91%).

The hydrazide (1.6 g, 0.01 mol) was added to KOH solution (8 mL, 4N) and was heated at 80 °C for 2 h (until it is soluble). The hot solution was filtered to remove insoluble materials. The filtrate was cooled and acidified using conc. HCl. The precipitated phenylurazole was isolated from solution by suction filtration and dried in vacuum to afford the urazole as colorless white powder (878 mg, 65%).

N-Phenylurazole (50 mg, 0.28 mmol) was dissolved in 3 mL ethyl acetate. To the solution tert-butyl hypochlorite (0.06 mL, 0.56 mmol) was added dropwise at 0 °C until the deep red colour appeared. It was further stirred for 1 h under nitrogen atmosphere and concentrated to furnish the N-phenyl-1,2,4-triazoline-3,5-dione in quantitative yield. The triazoline dione was used as such for the cycloaddition reactions.


A solution of 16 (50 mg, 0.08 mmol) and N-phenyl-1,2,4-triazoline-3,5-dione 45 (28 mg, 0.16 mmol) in dry toluene (5 mL) was stirred under an inert atmosphere at rt. The reaction mixture was stirred at this temperature until the
reaction was complete as indicated by TLC (6 h). The solvent was removed under reduced pressure and the residue was purified by silica gel column chromatography, to remove excess dienophile, using hexane-ethyl acetate (90:10) as the eluent to yield 46 (75 mg, 99%) as a white crystalline solid. The product was recrystallised from dichloromethane-acetonitrile mixture. m.p. decomposed > 274 °C.

IR (KBr) \( \nu_{\text{max}} \): 2957, 2856, 1762, 1712, 1363, 1345, 1256, 1234, 1219, 1093, 956 cm\(^{-1}\).

\(^1\)H NMR: \( \delta \) 7.52–7.37 (m, 1OH), 7.20 (s, 2H), 7.10 (s, 2H), 5.24 (s, 2H), 5.11 (d, \( J = 1.8 \) Hz, 2H), 4.28 (d, \( J = 15.3 \) Hz, 2H), 4.18 (d, \( J = 15.3 \) Hz, 2H), 3.63 (d, \( J = 16.5 \) Hz, 2H), 3.52 (d, \( J = 16.5 \) Hz, 2H), 1.33 (s, 18H), 1.07 (s, 18H).

\(^{13}\)C NMR: \( \delta \) 193.4, 154.6, 154.2, 152.3, 146.2, 131.2, 129.4, 128.8, 128.4, 125.9, 124.4, 121.5, 119.4, 118.1, 81.5, 67.8, 60.6, 37.1, 34.8, 33.9, 32.2, 29.9, 27.6, 26.5

MS (FAB, [M\(^+\)+H]): Calcd for C\(_{60}\)H\(_{62}\)N\(_6\)O\(_8\): 996.17; Found: 996.01.

6H,13H,20H,27H-5,27:13,19-Dietheno-5,26:10,12:12,19:24,26-tetramethano-
1H,15H-dibeno [1,9]bis[1,2,4] triazolo [1,2-d:1',2'-m][1,10,4,5,13,14]dioxa-
tetraazacyclooctadecin-1,3,15,17,32,35 (2H,16H)-hexone-8,22,29,34-tetrakis (1,1-
dimethylethyl)-2,16-dicyclohexyl [48]

Calix[4]bis(spirodieneone) 16 (50 mg, 0.08 mmol) was dissolved in dry
toluene (8 mL) under inert atmosphere. N-Cyclohexyl-1,2,4-triazoline-3,5-
dione 47 (29 mg, 0.16 mmol) was added to it and stirred at rt for 10 h. The
solvent was removed under vacuum and the residue subjected to silica gel
column chromatography using 85:15 hexane-ethyl acetate solvent mixture
affording 48 as a white solid (67 mg, 86%). m.p. decomposed > 272 °C.
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IR (KBr) $\nu_{\text{max}}$: 2931, 2789, 1764, 1711, 1482, 1405, 1372, 1365, 1256, 1201, 1159, 1109, 897 cm$^{-1}$.

$^1$H NMR: $\delta$ 7.16 (s, 2H), 7.09 (s, 2H), 5.12 (d, $J = 2.0$ Hz, 2H), 4.94 (d, $J = 2.0$ Hz, 2H), 4.16 (d, $J = 15.4$ Hz, 2H), 4.08 (d, $J = 15.4$ Hz, 2H), 3.74 (m, 2H), 3.54 (d, $J = 16.3$ Hz, 2H), 3.43 (d, $J = 16.3$ Hz, 2H), 2.03 (m, 4H), 1.80 (m, 4H), 1.63 (m, 6H), 1.34 (s, 18H), 1.25 (m, 6H), 0.98 (s, 18H).

$^{13}$C NMR: $\delta$ 193.4, 155.7, 155.4, 154.2, 151.6, 145.7, 128.2, 124.3, 121.1, 118.8, 118.1, 81.3, 67.2, 60.2, 52.7, 36.8, 34.5, 33.5, 31.9, 29.3, 27.4, 26.3, 25.8, 24.9.

MS (FAB, [M$^+$+H]): Calcd for C$_{60}$H$_{74}$N$_6$O$_8$: 1007.56; Found: 1007.54.

$^{6}$H$_{13}$H$_{20}$H$_{27}$H$_{5}$,26:10,12:12,19:24,26-tetramethano-1H,15H-dibenzo [1,9] bis[1,2,4] triazolo [1,2-d: 1’,2’-m][1,10,4,5,13,14]dioxa tetraazacyclooctadecin-1,3,15,17,32,35 (2H,16H)-hexone-8,22,29,34-tetrakis (1,1·dimethylethyl)-2,16-dibenzy1 [50]

A solution of 16 (50 mg, 0.08 mmol) and N-benzyl-1,2,4-triazoline-3,5-dione 49 (31 mg, 0.16 mmol) in dry toluene (5 mL) was stirred under an inert atmosphere at rt. The reaction mixture was stirred at this temperature until the reaction was complete as indicated by TLC (8 h). The solvent was removed under reduced pressure and the residue was purified by silica gel column chromatography, to remove excess dienophile, using hexane-ethyl acetate (90:10) as the eluent to yield 50 (78 mg, 99%) as a white crystalline solid. m.p. decomposed > 278 °C.

IR (KBr) $\nu_{\text{max}}$: 2955, 2914, 1758, 1711, 1556, 1540, 1455, 1430, 1326, 1310, 1109, 897 cm$^{-1}$. 
Diels-Alder reaction of bis(spirodienones)

**$^1$H NMR:** $\delta$ 7.33 (m, 10H), 7.15 (s, 2H), 7.10 (s, 2H), 5.05 (s, 2H), 4.95 (s, 2H), 4.56 (s, 4H), 4.17 (d, $J = 15.3$ Hz, 2H), 4.07 (d, $J = 15.3$ Hz, 2H), 3.50 (d, $J = 16.5$ Hz, 2H), 3.41(d, $J = 16.5$ Hz, 2H), 1.33 (s, 18H), 0.90 (s, 18H).

**$^{13}$C NMR:** $\delta$ 191.5, 153.9, 153.7, 153.0, 147.1, 145.3, 139.1, 130.8, 127.5, 127.2, 124.2, 121.5, 119.2, 117.1, 81.4, 68.6, 59.8, 44.4, 36.7, 34.6, 34.3, 33.7, 32.0, 29.9, 26.5.

**MS (FAB, [M]+H):** Calcd for $C_{62}H_{116}N_6O_8$: 1023.49; Found: 1023.22.

$^{1}$H, $^{13}$H, $^{20}$H, $^{27}$H-5, 27:13, 19-Dietheno-5, 26:10, 12:12, 19:24, 26-tetramethano-1H, 15H-dibenzo [1, 9] bis[1, 2, 4] triazolo [1, 2-d:1', 2'-m][1, 10, 4, 5, 13, 14] dioxatetraazacyclooctadecin-1, 3, 15, 17, 32, 34 (2H, 16H)-hexone-8, 22, 29, 34-tetakis (1, 1-dimethylethyl)-2, 16-bis(4-methoxybenzyl) [52]

Calix[4]bis(spirodienone) 16 (50 mg, 0.08 mmol) was dissolved in dry toluene (8 mL) under inert atmosphere. N-para-Methoxybenzyl-1, 2, 4-triazoline-3, 5-dione 51 (36 mg, 0.16 mmol) was added to it and stirred at rt for 8 h. The solvent was removed under vacuum and the residue subjected to silica gel column chromatography using 85:15 hexane-ethyl acetate solvent mixture affording 52 as a white solid (82 mg, 98%). m.p. decomposed > 260 °C.

**IR (KBr) $\nu_{max}$:** 2945, 2865, 1759, 1709, 1475, 1438, 1415, 1365, 1265, 1156, 1103, 927, 846 cm$^{-1}$.

**$^1$H NMR:** $\delta$ 7.27 (m, 4H), 7.14 (s, 2H), 7.09 (s, 2H), 6.80 (d, $J = 8.4$ Hz, 4H), 5.04 (s, 2H), 4.93 (s, 2H), 4.51 (s, 4H), 4.15 (d, $J = 16.8$ Hz, 2H), 4.06 (d, $J = 15.0$ Hz, 2H), 3.77 (s, 6H), 3.48 (d, $J = 16.8$ Hz, 2H), 3.39 (d, $J = 15.6$ Hz,
2H), 1.33 (s, 18H), 0.90 (s, 18H).

$^{13}$C NMR: $\delta$ 192.0, 159.0, 154.0, 153.1, 147.5, 130.4, 128.8, 127.8, 126.6, 124.5, 122.2, 119.5, 117.3, 115.2, 81.6, 68.7, 59.7, 56.1, 44.0, 36.9, 34.8, 34.4, 31.7, 30.2, 29.4, 26.4.

MS (FAB, $[M^+\text{]+H]}$): Calcd for C$_{64}$H$_{70}$N$_6$O$_{10}$: 1083.52; Found: 1083.64.

6H,13H,20H,27H-5,26:10,12:12,19:24,26-tetramethano-1H,15H-dibenzo[1,9]bis[1,2,4]triazolo[1,2-d:1',2'-m][1,10,4,5,13,14]dioxatetraazacyclooctadecin-1,3,15,17,32,35 (2H,16H)-hexone-8,22,29,34-tetrakis(1,1-dimethylethyl)-2,16-bis(4-methylbenzyl) [54]

To calix[4]bis(spirodienone) 16 (50 mg, 0.08 mmol) was added dry toluene (5 mL) and stirred under inert atmosphere. N-para-Methylbenzyl-1,2,4-triazoline-3,5-dione 53 (33 mg, 0.16 mmol) was added to it and the mixture stirred at rt for 10 h. The solvent was removed under vacuum and the residue subjected to silica gel column chromatography using hexane-ethyl acetate mixture (80:20) as the eluent to afford 54 as a white solid (80 mg, 98%). m.p. decomposed > 265 °C.

IR (KBr) $\nu_{max}$: 2959, 2901, 2845, 1745, 1713, 1483, 1437, 1409, 1201, 1169, 110 5, 950, 840, 756 cm$^{-1}$.

$^1$H NMR: $\delta$ 7.19 (m, 8H), 7.14 (s, 2H), 7.10 (s, 2H), 5.20 (d, $J = 1.9$ Hz, 2H), 5.17 (d, $J = 2.0$ Hz, 2H), 4.67 (s, 4H), 4.19 (d, $J = 15.4$ Hz, 2H), 3.99 (d, $J = 15.5$ Hz, 2H), 3.53 (d, $J = 16.2$ Hz, 2H), 3.36 (d, $J = 16.3$ Hz, 2H), 2.33 (s, 6H), 1.33 (s, 18H), 0.98 (s, 18H).

$^{13}$C NMR: $\delta$ 191.8, 153.8, 153.0, 147.1, 139.1, 130.8, 128.5, 128.2, 124.2, 121.8, 119.2, 117.1,
Diels-Alder reaction of bis(spirodienones)

81.3, 68.4, 59.4, 44.1, 36.6, 34.6, 34.1, 33.7, 32.1, 29.9, 29.6, 26.1, 20.9.

MS (FAB, M+): Calcd for C_{64}H_{76}N_{6}O_{8}: 1050.53; Found: 1050.57.

6H,13H,20H,27H-5,26:10,12:19:24,26-tetramethano-1H,15H-dibenzo [1,9] bis[1,2,4] triazolo [1,2-d:1',2'-m][1,10,4,5,13,14]dioxa tetraazacyclooctadecin-1,3,15,17,32,35 (2H,16H)-hexone-8,22,29,34-tetrakis (1,1-dimethylethyl)-2,16-bis(4-chlorobenzyl) [56]

A solution of 16 (50 mg, 0.08 mmol) and N-para-chlorobenzyl-1,2,4-triazoline-3,5-dione 55 (36 mg, 0.16 mmol) in dry toluene (5 mL) was stirred under an inert atmosphere at rt. The reaction mixture was stirred at this temperature until the reaction was complete as indicated by TLC (10 h). The solvent was removed under reduced pressure and the residue was purified by silica gel column chromatography using hexane-ethyl acetate (80:20) as the eluent to yield 56 (76 mg, 90%). m.p. decomposed > 255 °C.

IR (KBr) \( \nu_{\text{max}} \): 2955, 2897, 1763, 1713, 1485, 1435, 1410, 1356, 1254, 1199, 1099, 950, 844 cm\(^{-1}\).

\(^1\)H NMR: \( \delta \) 7.28 (m, 8H), 7.10 (s, 2H), 7.08 (s, 2H), 5.19 (s, 2H), 5.16 (s, 2H), 4.67 (s, 4H), 4.18 (d, \( J = 15.4 \) Hz, 2H), 3.97 (d, \( J = 15.5 \) Hz, 2H), 3.52 (d, \( J = 16.3 \) Hz, 2H), 3.36 (d, \( J = 16.3 \) Hz, 2H), 1.34 (s, 18H), 0.97 (s, 18H).

\(^13\)C NMR: \( \delta \) 191.7, 153.8, 152.8, 147.0 146.3, 135.2, 132.4, 128.5, 128.0, 126.2, 124.1, 121.8, 119.2, 117.0, 81.2, 68.3, 59.4, 43.5, 36.6, 34.6, 34.15, 32.6, 31.4, 29.9, 26.1.

MS (FAB, [M]+H): Calcd for C_{62}H_{64}Cl_{2}N_{6}O_{8}: 1091.42; Found: 1091.09.

Calix[4]bis(spirodienone) (16) with diethyl azodicarboxylate (57) to yield [58]
To calix[4]bis(spirodienone) 16 (50 mg, 0.08 mmol) was added dry toluene (5 mL) and the solution was stirred under inert atmosphere. Diethyl azodicarboxylate 57 (27 mg, 0.16 mmol) was added to it and the mixture heated at 110 °C for 7 h. The solvent was removed under vacuum and the residue subjected to silica gel column chromatography using hexane-ethyl acetate mixture (90:10) as the eluent to afford 58 as a white solid (70 mg, 90%). m.p. decomposed > 252 °C.

**IR** (KBr) \( \nu_{\text{max}} \): 2958, 2865, 1756, 1737, 1703, 1484, 1413, 1364, 1311, 1266, 1251, 1112, 843 cm\(^{-1}\).

**\(^1H\) NMR**: \( \delta \) 7.12 (s, 2H), 6.98 (s, 2H), 5.43 (s, 2H), 5.20 (s, 2H), 5.13 (d, \( J = 14.1 \) Hz, 2H), 4.97 (d, \( J = 14.1 \) Hz, 2H), 4.19 (m, 8H), 3.64 – 3.39 (m, 4H), 1.32 (s, 18H), 1.26 – 1.15 (m, 12H), 0.99 (s, 18H).

**\(^13C\) NMR**: \( \delta \) 196.9, 159.1, 154.9, 151.3, 144.7, 127.4, 126.9, 125.1, 124.9, 120.6, 119.2, 118.6, 84.3, 68.2, 63.1, 62.7, 56.3, 35.3, 35.2, 34.7, 31.9, 29.1, 27.8, 14.6.

**MS** (FAB, [M\(^+\)+H]): Calcd for C\(_{56}\)H\(_{72}\)O\(_{12}\)N\(_4\): 993.52; Found: 993.48.

Calix[4]bis(spirodienone)(16) with diisopropyl azodicarboxylate (59) to yield [60]

To calix[4]bis(spirodienone) 16 (50 mg, 0.08 mmol) was added dry toluene (5 mL) and was stirred under inert atmosphere. Diisopropyl azodicarboxylate 59 (33 mg, 0.16 mmol) was added to it and the mixture heated at 110 °C for 6 h. The solvent was removed under vacuum and the residue subjected to silica gel column chromatography using hexane-ethyl acetate mixture (90:10) as the eluent to afford 60 as a white solid (79 mg, 99%). m.p. decomposed > 256 °C.

**IR** (KBr) \( \nu_{\text{max}} \): 2960, 2878, 1754, 1740, 1486,
Diels-Alder reaction of bis(spirodielenones)

1412, 1320, 1276, 1257, 1165, 1115, 985 cm\(^{-1}\).

\(^1\)H NMR: \(\delta\) 7.23 (s, 2H), 7.01 (s, 2H), 5.41 (s, 2H), 5.22 (s, 2H), 4.91 (m, 4H), 4.17 (d, \(J = 15.0\) Hz, 2H), 3.62 (m, 2H), 3.45 (m, 2H), 3.34 (bs, 2H), 1.34 (s, 18H), 1.26 (m, 24H), 0.99 (s, 18H).

\(^{13}\)C NMR: \(\delta\) 193.1, 157.0, 156.2, 152.0, 151.7, 135.2, 127.3, 121.0, 88.6, 75.0, 74.5, 73.7, 73.1, 34.5, 33.7, 33.5, 31.6, 29.1, 26.9, 22.0, 21.7, 21.5, 21.3, 21.2, 18.7, 18.4.

MS (FAB, [M\(^+\)+H]): Calcd for C\(_{50}\)H\(_{80}\)N\(_4\)O\(_{12}\): 1049.58; Found: 1049.25.

2.6 References


