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The reactivity of *o*-quinones and other 1,2-diones towards a variety of dipolar species *viz.*, nitrile oxides, carbonyl ylides, betaines and mesoionic compounds has been investigated. In most cases, these reactions occur with the participation of C=O group as the dipolarophile leading to the synthesis of novel heterocyclic compounds.

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### Introduction.

The chemistry of *o*-quinones, especially their cycloadditions, has been a subject of considerable interest [1,2]. In Diels-Alder reactions *o*-benzoquinone can participate as carbodiene, heterodiene, carbodienophile or heterodienophile. Recent investigations in our laboratory have underscored the importance of electronic and steric factors on the cycloaddition reactions of *o*-quinones [3].

As a natural progression of our work on the Diels-Alder reactions of *o*-quinones, we became interested in the dipolar cycloadditions of the latter. The results of our investigations in this area concerned with novel heterocyclic construction are presented in this paper.

The presence of two potentially dipolarophilic functionalities, *i.e.* C=C and C=O, renders *o*-quinones very interesting from the vantage-point of dipolar cycloaddition. Although such reactions can conceivably lead to novel heterocyclic compounds, there has been very little information available on the reaction of *o*-benzoquinones with various dipoles; the available data is restricted to the reactions of diazomethane and certain mesoionic compounds [2,4].

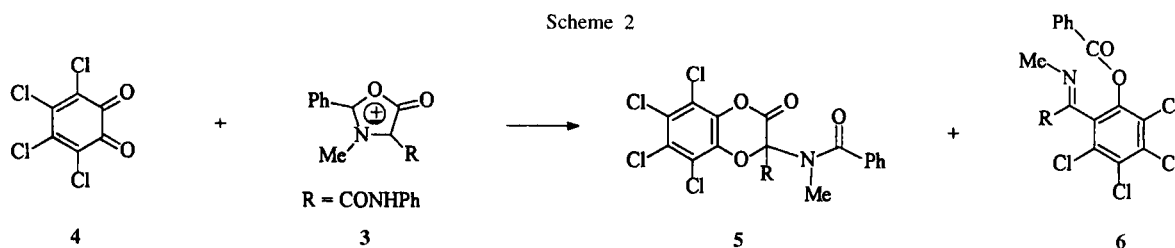
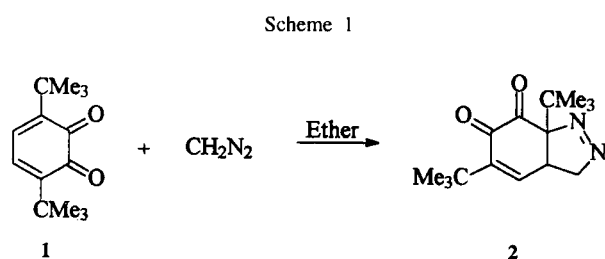
The reaction of 3,6-di-*tert*-butyl-1,2-benzoquinone **1** with diazomethane has been reported to afford the indazole **2** (Scheme 1) [5].

The reaction of münchnone **3** with *o*-chloranil **4** in acetonitrile yielded only the lactone **5**, while the same reactants in benzene afforded **5** and **6** (Scheme 2) [6].

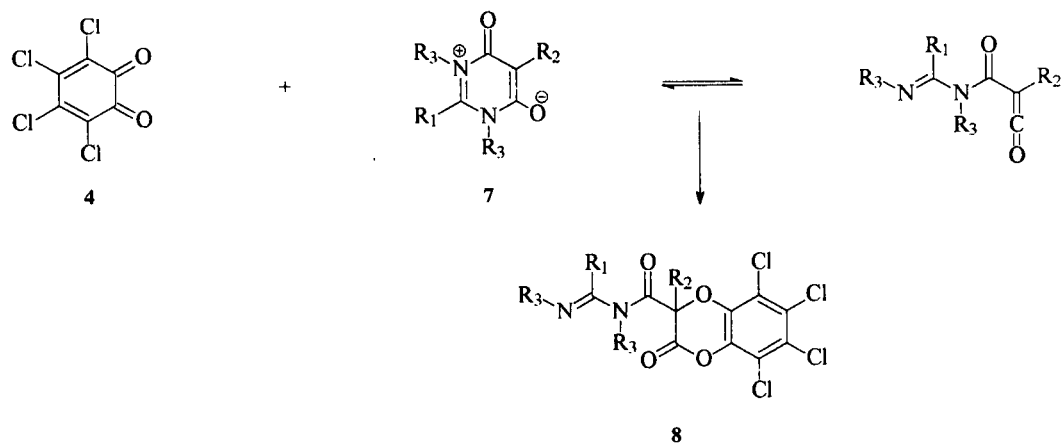
Reaction of *o*-chloranil and 1,3-disubstituted-3,6-dihydro-6-oxopyrimidinium-4-olates **7** also proceeded in a similar pathway (Scheme 3) [7-8].

The reaction of 4-oxo-4*H*-1,3-oxazinium-6-olates **9** with *o*-chloranil **4** leads to the formation of **10** (Scheme 4) [8]. Similar reaction occurs with *o*-benzoquinone also [9].

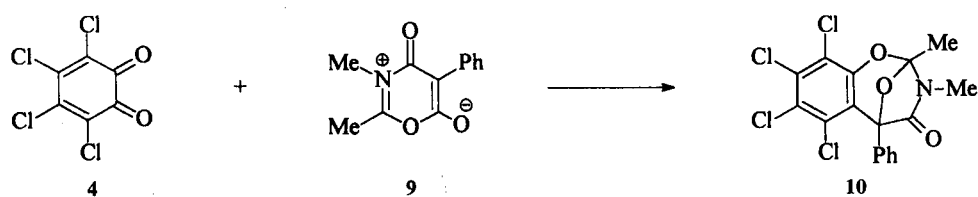
Isolated and sketchy investigations of 1,3-dipolar cycloadditions of nitrile *N*-oxides with *o*-bromanil **11** and *o*-benzoquinone **12** have been reported and the products were assigned structures without definitive supporting data. For instance, *o*-benzoquinone and *o*-bromanil have been reported to give the tris adduct **14** and the bis adduct **15**, respectively, on reaction with nitrile oxide **13** (Scheme 5) [10].



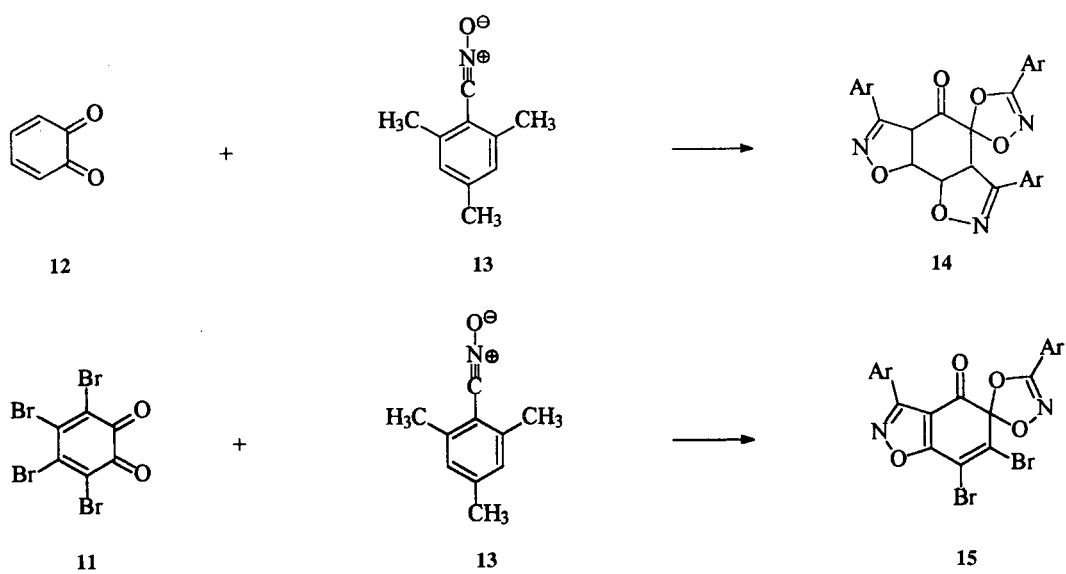
Scheme 3



Scheme 4



Scheme 5



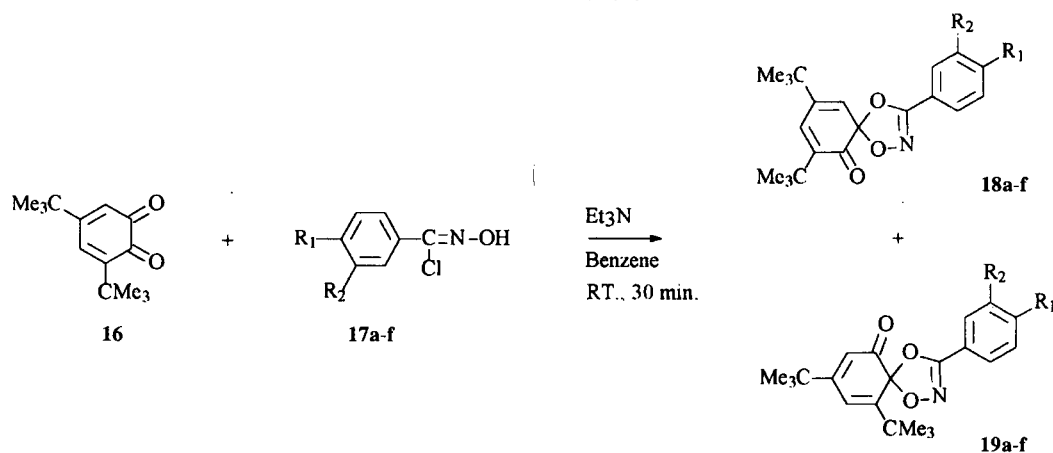
It is clear from the literature survey presented above that the information available on the dipolar cycloaddition of *o*-benzoquinones with various dipoles is very limited. Furthermore, the isolated examples of cycloaddition reported are not well documented and involved in most cases *o*-chloranil and *o*-bromanil only. These studies are clearly inadequate to attest the generality, scope and mechanism of the dipolar cycloaddition of *o*-quinones. We therefore undertook a systematic investigation of the dipolar cycloaddition reactions of various substituted *o*-benzoquinones with dipoles such as nitrile oxides and carbonyl ylides [11].

## Results and Discussion.

### Cycloaddition of Nitrile *N*-Oxides with *o*-Benzoquinones.

Our studies were initiated with the cycloaddition reaction of *p*-tolyl nitrile oxide **17a** with 3,5-di-*tert*-butyl-1,2-benzoquinone **16**. The reaction proceeded smoothly affording the regioisomeric mixture of spiro-1,3-dioxazoles **18a** and **19a**. The products were separated by silica gel column chromatography and characterized by spectral analysis and ultimately by single crystal X-ray analysis of **19a** [12]. Similar reactivity was observed with **16** and various nitrile oxides **17b-f** and the results are summarized below (Scheme 6).

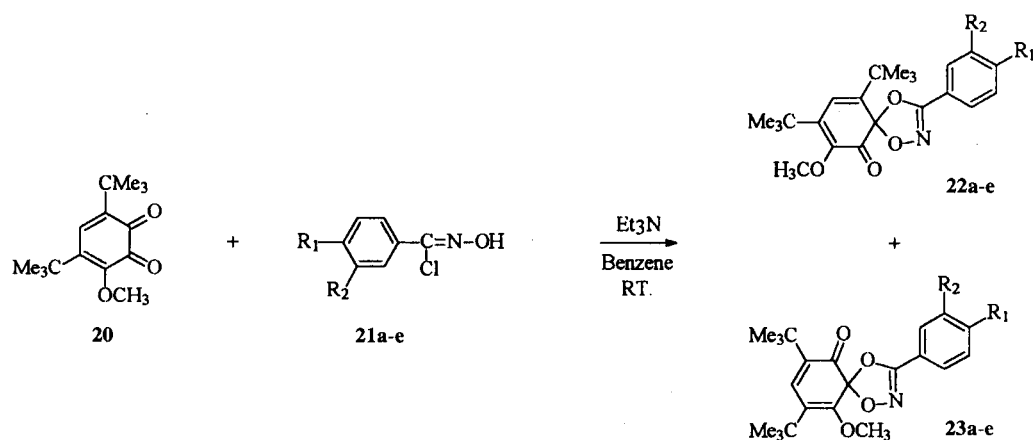
Scheme 6



a. R<sub>1</sub> = CH<sub>3</sub>; R<sub>2</sub> = H; **18a:19a** (3:1); 80%; b. R<sub>1</sub> = OCH<sub>3</sub>; R<sub>2</sub> = H; **18b:19b** (1:1); 100%; c. R<sub>1</sub> = R<sub>2</sub> = OCH<sub>3</sub>; **18c:19c** (1:1); 99%; d. R<sub>1</sub> = Cl; R<sub>2</sub> = H; **18d:19d** (1.6:1); 83%; e. R<sub>1</sub> = H; R<sub>2</sub> = Cl; **18e:19e** (2:1); 100%; f. R<sub>1</sub> = R<sub>2</sub> = H; **18f:19f** (1:1); 99%.

Analogous reactivity was observed with 3-methoxy-4,6-di-*tert*-butyl-1,2-benzoquinone **20** and various nitrile oxides **21a-e**. The results are summarized below (Scheme 7).

Scheme 7

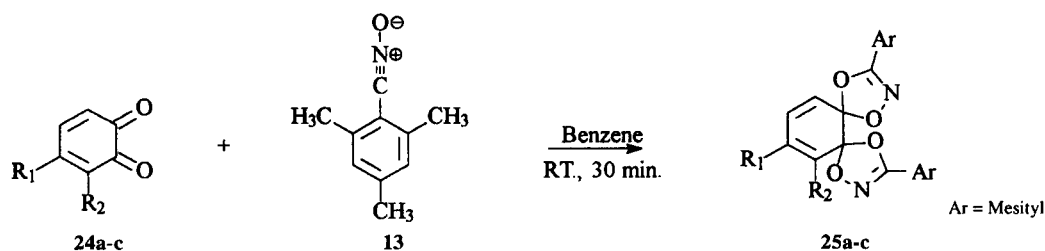


a. R<sub>1</sub> = CH<sub>3</sub>; R<sub>2</sub> = H; **22a:23a** (1:1); 100%; b. R<sub>1</sub> = H; R<sub>2</sub> = Cl; **22b:23b** (1:1); 96%; c. R<sub>1</sub> = H; R<sub>2</sub> = NO<sub>2</sub>; **22c:23c** (1:1); 97%; d. R<sub>1</sub> = R<sub>2</sub> = OCH<sub>3</sub>; **22d:23d** (1:1); 100%; e. R<sub>1</sub> = Cl; R<sub>2</sub> = H; **22e:23e** (1:1) 98%.

The reaction of 4-methyl and 3-methoxy-1,2-benzoquinones, generated *in situ* from the corresponding catechols by silver carbonate oxidation, with nitrile oxides **21a-e** resulted in complex mixtures. However, the reaction with mesityl nitrile oxide **13** proceeded smoothly. For instance, 4-methyl-1,2-benzoquinone **24a** on treatment with **13** afforded the bisspirodioxazole **25a**. Similar reactivity was observed with 4-*tert*-butyl-1,2-benzoquinone **24b** (Scheme 8).

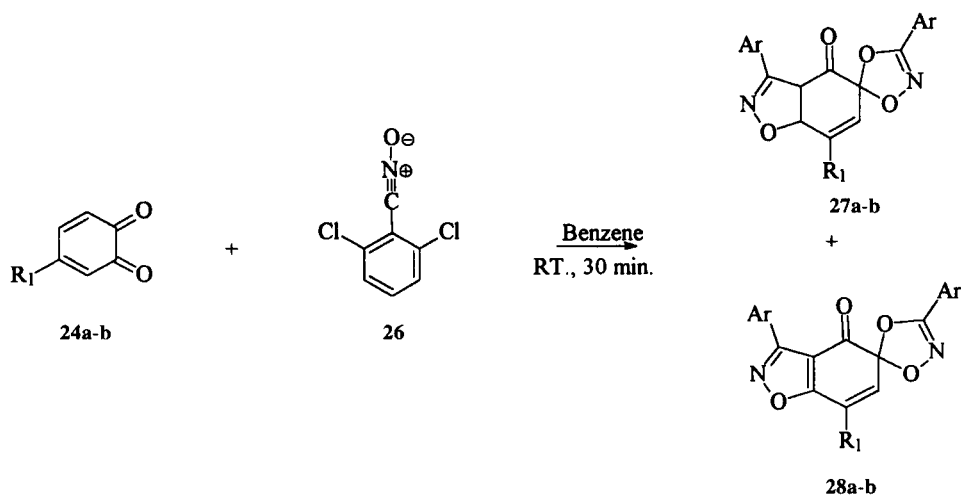
The reaction of 4-*tert*-butyl-1,2-benzoquinone **24b** with 2,6-dichlorobenzonitrile oxide **26** afforded the bis adducts (Scheme 9). The structures **27b** and **28b** were assigned by spectral analysis and finally confirmed by single crystal X-ray analysis of **28b**. The same reactivity pattern was observed with 4-methyl and 3-methoxy-1,2-benzoquinones **24a,c** (Scheme 9).

Scheme 8

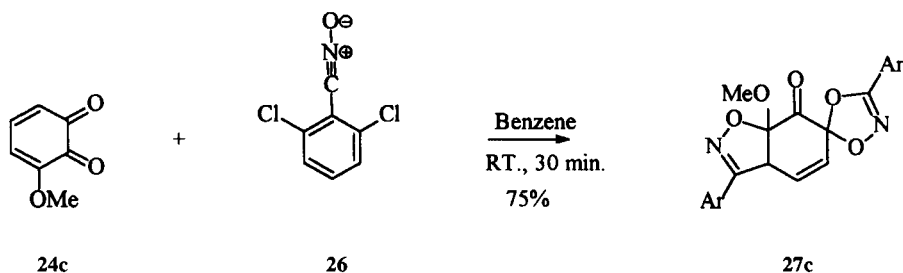


a.  $\text{R}_1 = \text{CH}_3$ ;  $\text{R}_2 = \text{H}$ ; 49%; b.  $\text{R}_1 = \text{CMe}_3$ ;  $\text{R}_2 = \text{H}$ ; 69%; c.  $\text{R}_1 = \text{H}$ ;  $\text{R}_2 = \text{OMe}$ ; 59%.

Scheme 9



a.  $\text{R}_1 = \text{CH}_3$ ; 80% (4.3:1); b.  $\text{R}_1 = \text{CMe}_3$ ; 59% (2.5:1).



Thus, di- and trisubstituted *o*-benzoquinones form a mixture of monospirodioxazoles by addition of nitrile oxide to the carbonyl group. The fact that no addition of nitrile oxide occurs to the C=C bond may be attributed to the steric hindrance imparted by the substituents on the quinone. In the case of monosubstituted 1,2-benzoquinones, mesitylnitrile oxide forms bis-spirodioxazole derivatives, while 2,6-dichlorobenzonitrile oxide affords bis adducts by participation of C=C and C=O bonds. This difference in reactivity may be attributed to electronic effects of the substituents on the nitrile oxide. It may be pointed out that monospirodioxazole formation may be exploited as a means to obtain partially protected *o*-benzoquinones.

#### Cycloaddition Reaction of Carbonyl Ylide with *o*-Quinones.

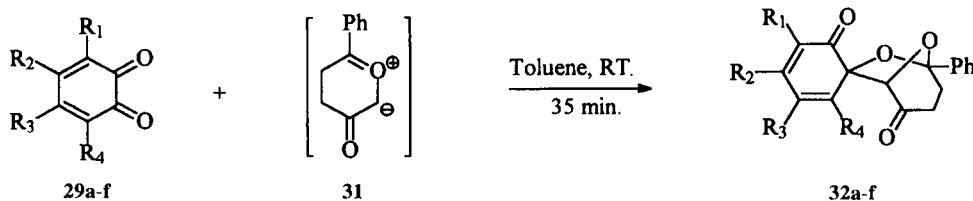
Subsequent to our studies on dipolar cycloaddition reactions of nitrile oxides with *o*-quinones, we have

probed the reactivity of carbonyl ylides towards *o*-quinones. The ylide **31** generated from 1-diazo-5-phenyl-2,5-pentanedione **30** [11], on reaction with 3,5-di-*tert*-butyl-1,2-benzoquinone **29a**; afforded a novel highly oxygenated spirocyclic compound **32a** (Scheme 10) [13]. The product was characterized by the usual spectral methods and ultimately by single crystal X-ray analysis of **32a**. The reaction occurs smoothly with various *o*-quinones and in all cases the spiro heterocycles were obtained. The results are summarized below (Scheme 10).

The reaction is applicable to acenaphthenequinone also. Trapping the dipole **31a** with acenaphthenequinone **33** afforded a mixture of isomers in 67% overall yield as shown in Scheme 11. The structure of one of the isomers **34** was confirmed by X-ray analysis.

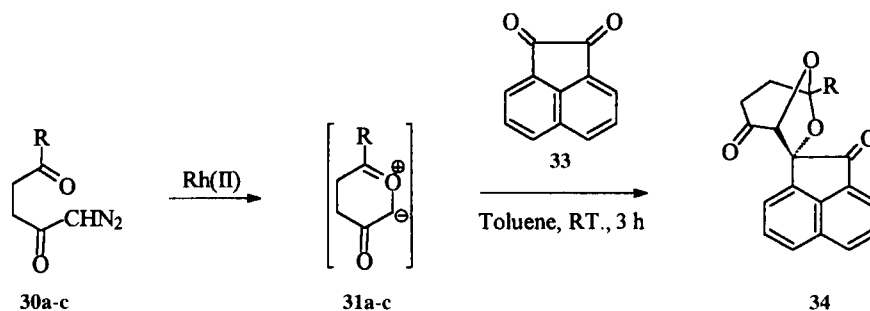
The success of the cycloaddition of carbonyl ylides to *o*-quinones prompted us to investigate their reaction with other 1,2-diones. A group of 1,2-diones that appeared

Scheme 10



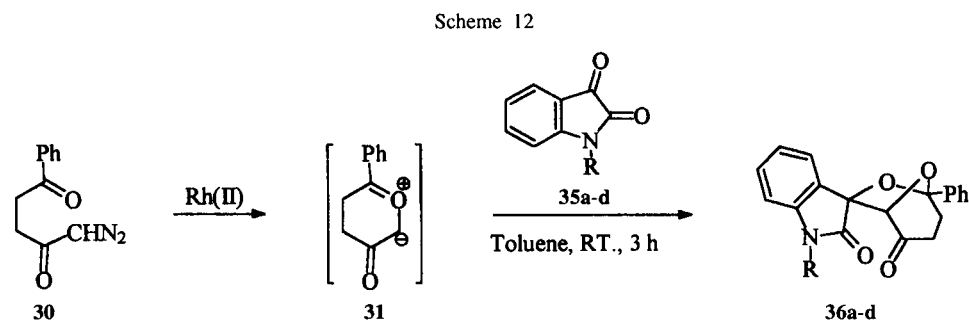
a.  $R_1 = R_3 = \text{CMe}_3$ ,  $R_2 = R_4 = \text{H}$ ; 76%; b.  $R_1 = R_3 = \text{CMe}_3$ ,  $R_4 = \text{OMe}$ ,  $R_2 = \text{H}$ ; 61%; c.  $R_1 = R_2 = \text{H}$ ,  $R_3 = \text{Me}$ ,  $R_4 = \text{Me}$ ; 48%; d.  $R_1 = R_2 = \text{H}$ ,  $R_3 = \text{Me}_3$ ; 42%; e.  $R_1 = R_3 = \text{CHPh}_2$ ,  $R_2 = \text{H}$ ,  $R_4 = \text{OMe}$ ; 41%; f.  $R_1 = R_2 = \text{Benzo}$ ,  $R_3 = R_4 = \text{Benzo}$ ; 37%.

Scheme 11

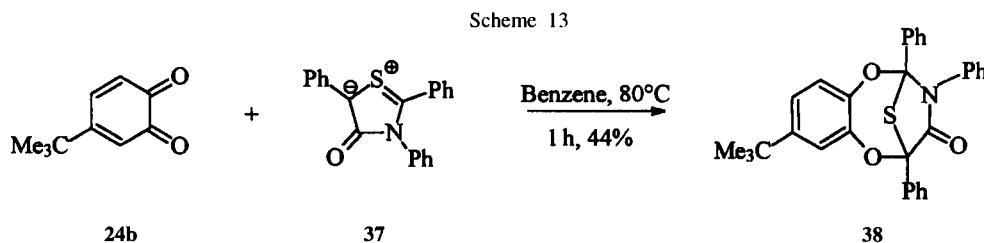


a.  $R = \text{Ph}$ , 67%, (1.3:1); b.  $R = \text{C}_6\text{H}_4\text{-CH}_3$ , 70%, (3:1); c.  $R = \text{C}_6\text{H}_4\text{-OMe}$ , 61%, (1:1.6).

very interesting in this context is the isatins. The carbonyl ylide from 1-diazo-5-phenyl-2,5-pentanedione generated in the usual manner on reaction with *N*-phenyl isatin **35a** afforded the cycloadduct **36a** in 75% yield. The reaction appears to be general (Scheme 12).

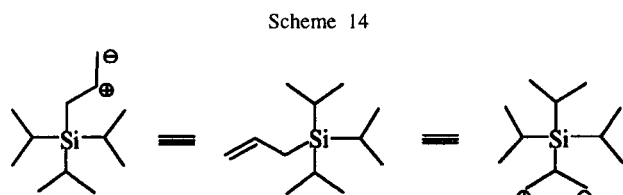


Mesoionic compounds [14] such as thioisomünchnones [15] and sydones also react with *o*-quinones. The following example is illustrative for thioisomünchnones **37** (Scheme 13).



Dipolar Cycloaddition Reactions of Allylsilanes with *o*-Benzoquinones.

Allylsilanes are excellent reagents for the regio- and stereoselective formation of carbon-carbon bonds [16-17]. Allylsilanes having bulky substituents on silicon is known to function as an equivalent of silyl substituted 1,3- or 1,2-dipole toward activated double or triple bonds (Scheme 14).



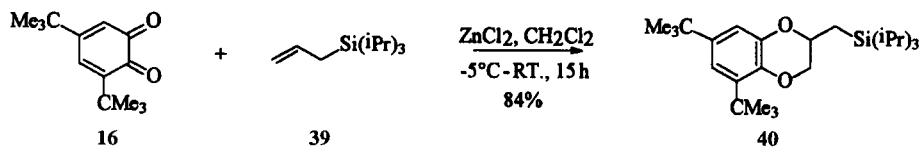
Much of the work in this area is influenced by the work of Knölker, who has clearly demonstrated the utility of allylsilanes in synthetic organic chemistry including application to natural product synthesis [18].

As a part of our program aimed at understanding the reactivity of *o*-benzoquinones toward dipoles, we undertook an investigation of their reaction with allylsilanes.

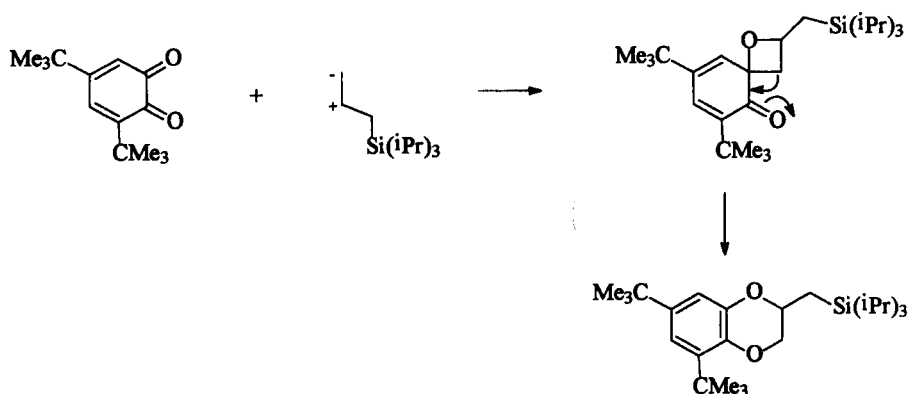
3,5-Di-*tert*-butyl-1,2-benzoquinone **16** on treatment with allyl triisopropylsilane in the presence of zinc chloride afforded a product in 84% yield. This was tentatively characterized as the benzodioxin **40**. The reaction can be illustrated as follows (Scheme 15).

The formation of benzodioxin discussed above can be rationalized by invoking the participation of allylsilane as a 1,2-dipole. The latter can conceivably add to the carbonyl group forming an oxetane intermediate, which then undergoes rearrangement to form the benzodioxin (Scheme 16). The net result may be viewed as a [4 + 2] dipolar cycloaddition reaction of an allylsilane to *o*-benzoquinone.

Scheme 15



Scheme 16

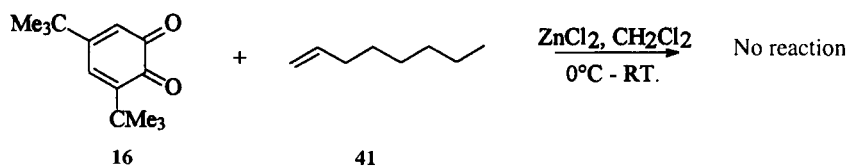


Indirect evidence supporting the proposed mechanism was obtained from the following experiments. The reaction of allyl triisopropylsilane with 3,5-di-*tert*-butyl-1,2-benzoquinone **16** in the absence of Lewis acids did not lead to any isolable product. The reaction of allyltriisopropylsilane and 3,5-di-*tert*-butyl-1,2-benzoquinone under thermal conditions was also unsuccessful.

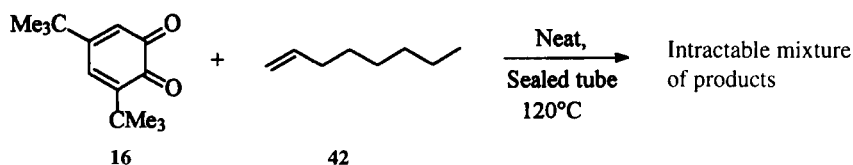
In addition, alkenes as exemplified by 1-octene **41** does not react with 3,5-di-*tert*-butyl-1,2-benzoquinone **16** in presence of zinc chloride (Scheme 17).

The reaction of 3,5-di-*tert*-butyl-1,2-benzoquinone **16** and 1-octene **42** under thermal conditions (sealed tube,  $130^\circ\text{C}$ , 12 hours) resulted in the formation of an intractable mixture of products (Scheme 18).

Scheme 17



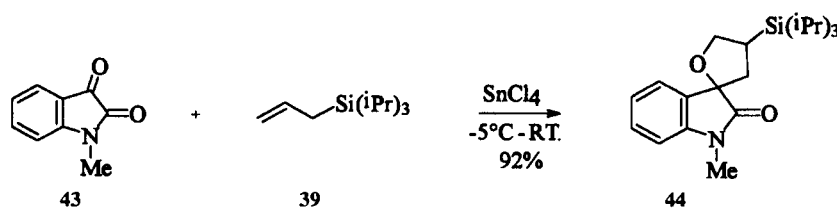
Scheme 18



The above experiments lead to the conclusion that in all likelihood, the reaction of allyltrisopropylsilane with *o*-benzoquinone involves the intermediacy of a silyl substituted 1,2-dipole.

The allylsilane **39** has been found to react with isatin **43** to afford a product tentatively identified as the spirofuran **44** (Scheme 19).

Scheme 19



In addition to the cycloadditions of dipoles to 1,2-dicarbonyl compounds, in this paper, we wish to report two related reactions involving betaines and *o*-quinones.

The first one is the addition of a betaine generated from triphenylphosphine and dimethyl acetylenedicarboxylate. The addition of triphenylphosphine to electron deficient alkynes, leading to zwitterionic compounds and the subsequent reactions of the latter species, notably dimerization, has been known from the work of Tebby and co-workers [19a-b]. Very recently dimethyl acetylenedicarboxylate has been reported to add to activated carbonyl compounds such as  $\alpha$ -ketoesters and  $\alpha$ -ketonitriles under the influence of triphenylphosphine to afford  $\gamma$ -lactones [20].

We have now found that the reaction of dimethyl acetylenedicarboxylate **45** with *o*-quinones in the presence of triphenylphosphine proceeds smoothly to afford spiro lactones **46** [21]. The following example is illustra-

tive (Scheme 20). The structure of the spiro lactone was confirmed on the basis of spectral and analytical data and finally by X-ray crystallography.

The spiro lactone formation can be rationalized as shown in Scheme 21.

Similar results were obtained with a number of other *o*-quinones [21].

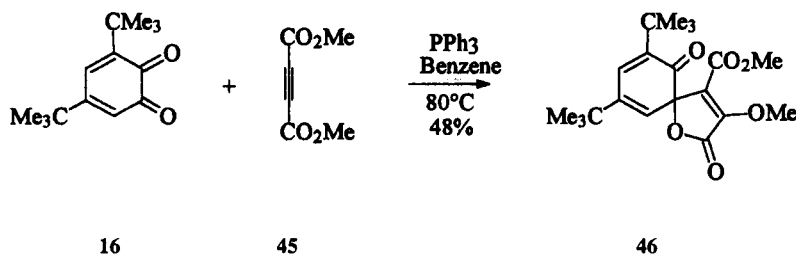
The reaction is applicable to 1,4-quinones also (Scheme 22).

Very recently we have observed a similar three component reaction involving isonitrile, dimethyl acetylenedicarboxylate [22] and *o*-quinones. An illustrative example is given as follows (Scheme 23).

A mechanistic rationale for the reaction may be given as follows (Scheme 24).

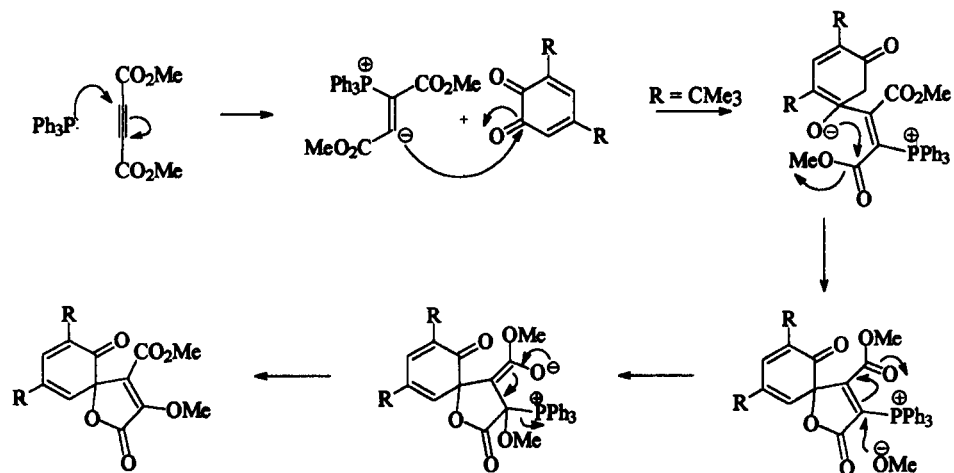
This reaction also appears to be general. Further work is in progress.

Scheme 20

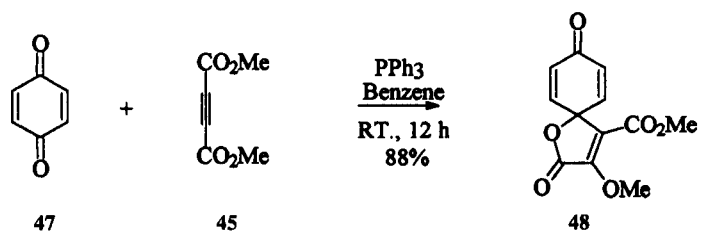




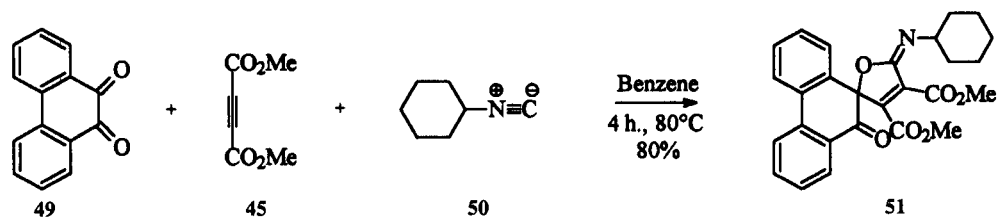
Scheme 21



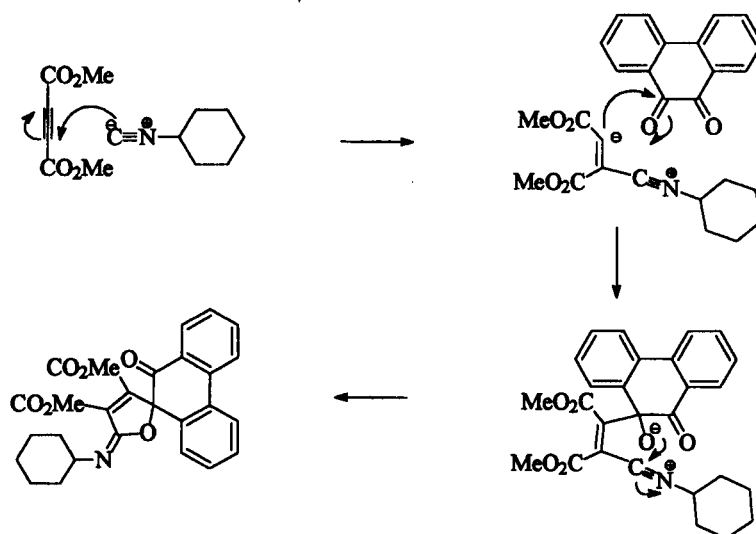
Scheme 22



Scheme 23



Scheme 24



### Conclusion.

In conclusion, we have encountered some novel reactivity patterns of 1,2-diones such as *o*-benzoquinones and isatins towards various dipolar species. In the process, facile synthesis of a variety of interesting heterocyclic compounds has been achieved. It is conceivable that further explorations in the area of dipolar cycloaddition to 1,2-diones will be rewarding from the synthetic and mechanistic standpoints.

### Acknowledgements.

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