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CORRELATION BETWEEN SITESELECTIVITY AND HOMO-LUMO ENERGY SEPARATION; EVIDENCE FOR RAPID EQUILIBRIUM OF QUINONOID KETENES VIA BENZOCYCLOBUTENONE

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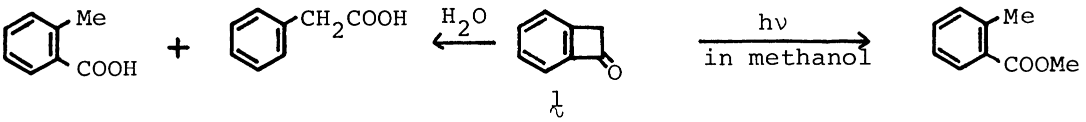
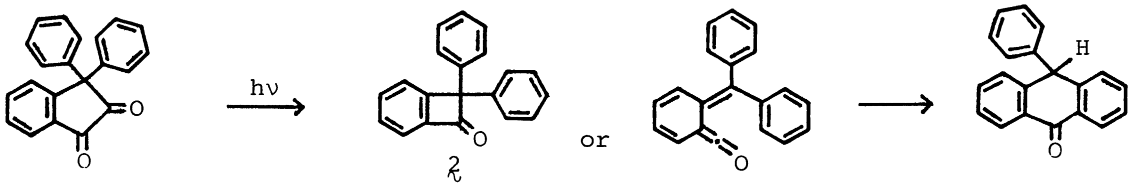
Evidence for rapid equilibrium between two isomeric 9,9-diaryl quinonoid ketenes via benzocyclobutenone was presented on the basis of the correlation between siteselectivity and HOMO-LUMO energy separation on their intramolecular cycloadditions

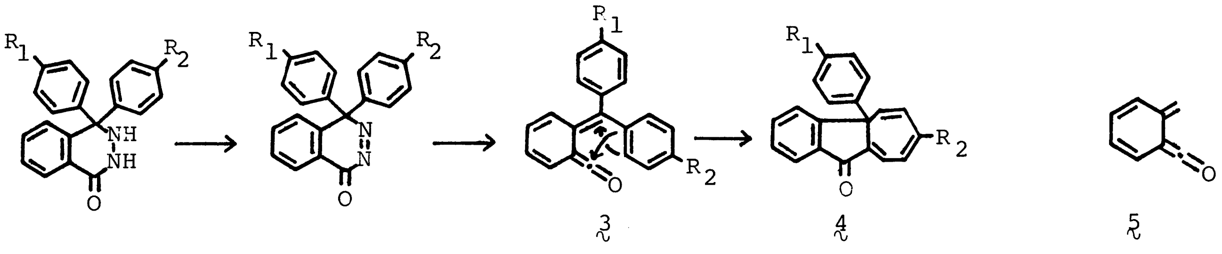
Benzocyclobutenone, **1**, is thermally stable and isolable molecule at room temperature. Thus, **1** has been reported to undergo base-catalyzed ring cleavage under mild conditions to afford a mixture of o-toluic acid and phenylacetic acid,[1] and also, ultraviolet irradiation of **1** in methanol gave methyl o-toluate,[2] which is probably formed via the quinonoid ketene.



On the other hand, 2,2-diphenylbenzocyclobutenone, **2**, has not yet been isolated,[3] and has only been postulated as one candidate for the intermediate of photochemical transformation of 3,3-diphenyl-1,2-indandione into an anthrone derivative, along with the valence isomeric quinonoid ketene.[4]

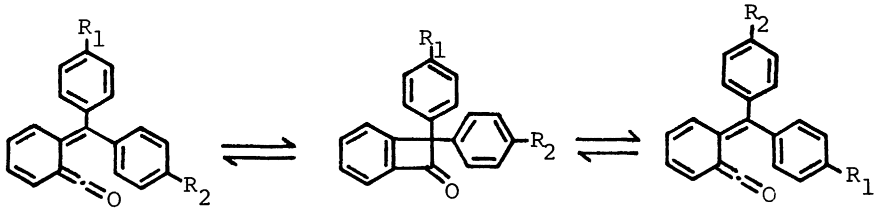


Recently, we have demonstrated that the quinonoid ketene, **3**, underwent a novel regiospecific [$_{\pi}4_a + _{\pi}2_a$] intramolecular cycloaddition with N,N-dimethylanilino group to result in the formation of an azulenone derivative, **4**,[5] and this regiospecificity can be nicely rationalized in terms of frontier molecular orbital theory by separating the quinonoid ketene, **3**, into two moieties; quinonoid ketene, **5**, for diene segment and dimethylanilino group for dienophile segment.[6]



If each benzene ring on the quinonoid ketene, **3**, bears a different substituent at the para position ($R_1 \neq R_2$), the cyclization of such ketenes would provide an experimental criterion on the siteselectivity for choosing as to which aromatic ring participates in the cyclization.

We have examined the cyclization using such quinonoid ketenes, generated similarly from the corresponding 4,4-diaryl-3,4-dihydro-1(2H)-phthalazinones by low temperature LTA oxidation, and wish to present here the evidence that the quinonoid ketene, **6** and **7**, are extremely rapidly interconverting each other probably through the valence isomeric benzocyclobutenone, **8**, deduced by the excellent correlation between siteselectivity and HOMO-LUMO energy separation on their intramolecular cycloadditions. No evidence for existence of such equilibrium has yet been shown previously.



6 **8** **7**

The molecular orbital energy and coefficient of mono-substituted benzenes examined were calculated by CNDO/2 method for comparison with the same level of approximation.[7] The FMO energy separation between the quinonoid ketene, **5**, previously calculated [6] and the several mono-substituted benzenes were shown in Table I.[8] Inspection of Table I clearly indicated that, only in the case of those with anilino groups, the LUMO of the quinonoid ketene, **5**, could be involved in the intramolecular cycloadditions.[9]

Table I. FMO energy separation (eV) between quinonoid ketene, **5**, and several mono-substituted benzenes calculated by CNDO/2 method

Mono-Substituted Benzene	LUMO(ketene)-HOMO(aromatics)	LUMO(aromatics)-HOMO(ketene)
Diethylaniline	12.628	13.574
Dimethylaniline	12.826	13.512
Anisole	14.362	13.346
Toluene	14.762	13.304
Benzene	15.896	13.513

Thus, one can believe that the intramolecular cycloaddition of quinonoid ketene, **6**, with the other aromatic ring would undergo a normal 6π-electrocyclization to give an anthrone derivative in view of the distribution of the HOMO coefficient of quinonoid ketene, **5**.[6]

In fact, the intramolecular cycloaddition of **6**, when the para-substituent on the 9-aryl group is either methoxy or methyl, did yield neither benzoazulenone derivative nor any product derived from such a compound to result merely in the formation of anthrone derivatives.[10] However, the experimental results,[10] as summarized in

Table II, revealed that the product ratio ($P={}^{P}2/{}^{P}1$)[11] to the one derived from the cyclization with N,N-dimethylanilino group is totally proportional to the smaller pair of the FMO energy separation between the quinonoid ketene, 5, and the aromatic segment.

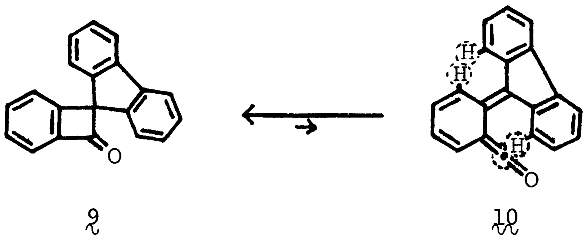
Table II. Product ratio ${}^{P}2/{}^{P}1$ on the intramolecular cycloaddition of 9,9-diaryl quinonoid ketene

Quinonoid ketene		Product ratio ${}^{P}2/{}^{P}1$
6a: $R_1=N(Et)_2$,	$R_2=N(Me)_2$	1.11
3 : $R_1=R_2=N(Me)_2$		1.00
6b: $R_1=N(Me)_2$,	$R_2=Me$	0.33
6c: $R_1=N(Me)_2$,	$R_2=OMe$	0.30
6d: $R_1=N(Me)_2$,	$R_2=H$	0.23

The plot of log P as a function of the smaller pair of HOMO-LUMO energy separation showed the liner relation, regardless of cyclization course, as shown in Figure I.[12]

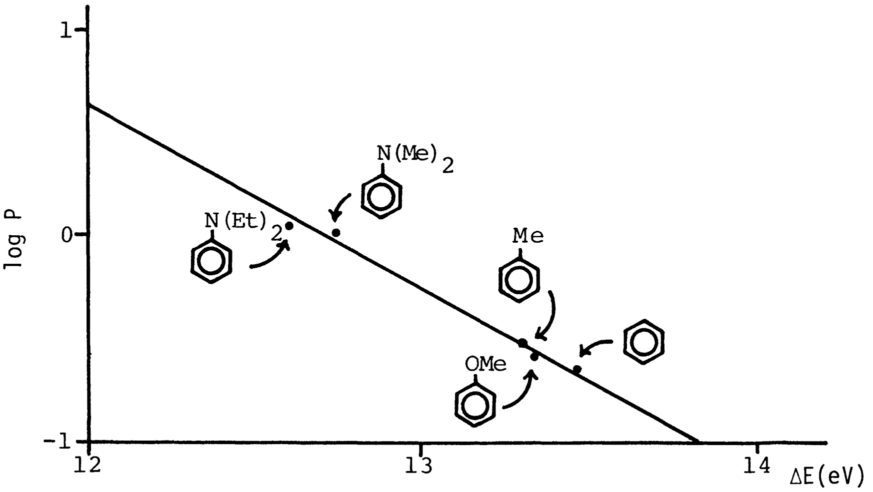
These results are strongly suggestive for rapid equilibrium between the two quinonoid ketenes, 6 and 7, which most likely occurs via benzocyclobutenone, 8, since only one of the two aromatic portions (an aromatic ring bearing R_2 in 6, and the one bearing R_1 in 7) can geometrically undergo the cyclization, and it is highly unlikely for the substituent at the para position in the aromatic ring of 6 (or 7) to affect sterically the ratio of abundance of the ketene, 6 and 7. Thus, the rate of the cyclization must reflect the product ratio, as the product ratio have varied depending on the variation of the para substituent of the benzene ring.

The great stabilization by conjugative interaction of the two aromatic rings on the side of quinonoid ketene form, 6 and 7, relative to benzocyclobutenone form, 8, would be responsible for the rapid equilibrium via benzocyclobutenone. It should be noted, however, that, based on our previous conformational studies of cis-cis-diene-ketene, aromatic ring of 6 (and 7) are substantially rotated with respect to the quinonoid ketene plane, and rotation of the aromatic ring toward the plane conformer results in a steep energy increase.[6] This conformational feature accounts actually for an isolable stability of fluorene-9-spirobenzocyclobutenone, 9,[3] due to very high electron- and core-repulsive contribution of the coplanar fluorene moiety to destabilization of the valence-isomerized ketene form, 10, despite the contribution of full conjugation.



9 10

Figure I. Plot of products p_2 and p_1 vs. HOMO-LUMO energy separation.



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1. M. P. Cava and K. Muth, J. Am. Chem. Soc., **82**, 652 (1960).
2. M. P. Cava and R. J. Spangler, ibid., **89**, 4550 (1967); see also, H. A. Staab and J. Ipaktschi, Tetrahedron Lett., 583 (1966).
3. Closely related compound, fluorene-9-spirobenzocyclobutenone, **9**, has been isolated (vide infra); H. Iwamura and H. Tukada, ibid, 3451 (1978).
4. J. Rigaudy and N. Pailloud, ibid., 4825 (1966).
5. M. Kuzuya, F. Miyake, and T. Okuda, ibid., 1043 (1980).
6. M. Kuzuya, F. Miyake, and T. Okuda, ibid., 2185 (1980).
7. In all cases, the standard bond lengths were used for the geometrical parameters; see, J. A. Pople and D. L. Beveridge, "Approximate Molecular Orbital Theory", McGraw Hill, New York (1970), p 111.
8. Calculation on the out of plane deformation of the full molecule **6** (or **7**) introduces the complexity of σ-π mixing, which gives orbitals of unrecognizable shapes. Therefore, we separate the molecule into two components; the quinonoid ketene, **5**, as 4π-component and aromatic as 2π-component.
9. This method may be oversimplified to draw the overall picture of the intramolecular cycloaddition. However, it has proven useful in our hand for gaining insight into the regiochemistry of the intramolecular cycloaddition.[4] Thus, we applied the same method for the cases reported herein.
10. All new compounds reported herein gave a satisfactory elementary analysis. Focussing our attention on the behavior of the cyclization in this communication, we defer the discussion of the structural identification, which will be reported in a full paper.
11. p_2 is the relative chemical yield of the product derived from the cyclization with the aromatic ring bearing R_2 substituent, and p_1 is that derived from the cyclization with N,N-dimethylanilino group, and the product ratios were directly determined by NMR integration of the reaction mixture.
12. The straight line obtained by a least squares method may be expressed as log P = $-0.835\Delta E + 10.644$, and a coefficient of correlation (r) was obtained as r = -0.990.

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