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Photochemical Additions of Alkenes to *N*-Methylphthalimides. Effect of Aryl Substituents on the Direction of Addition

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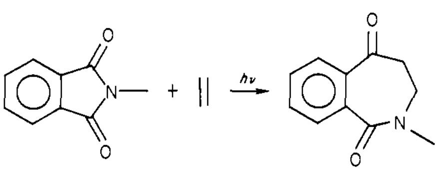
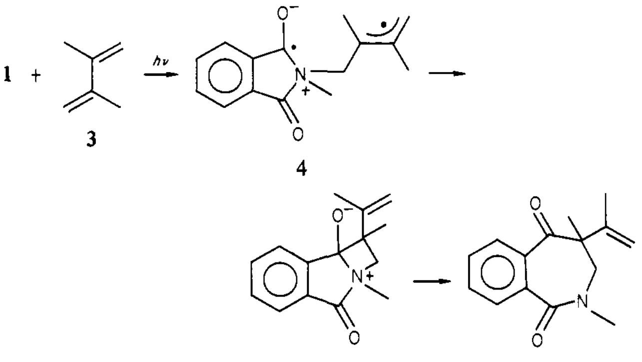
Since its original discovery,[1,2] the photochemical addition reaction of ene components to *N*-methylphthalimide affording benzazepinediones (**1** → **2**) has been the subject of a number of investigations to delineate its scope and mechanism.[2-11] The initial reaction involving dienes has been extended to include alkenes,[3-5] vinyl ethers,[6] vinyl esters,[7] and allenes,[8] although the number of examples in the last three categories is quite limited.



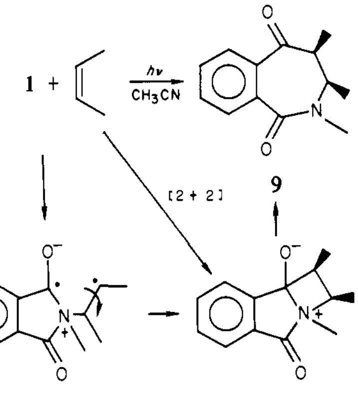
1 **2**

Mechanistic speculation must be consistent with the fact that the direction of addition of the ene component is best rationalized by consideration of the stability of a hypothetical radical intermediate (**4**), i.e., the product that results can be best rationalized

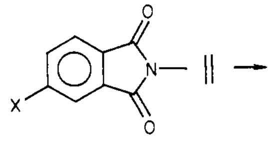


by assuming addition of the ene component to the nitrogen atom to give the most stable biradical. Frontier molecular orbital reasoning suggests the same orientation. Subsequent mechanistic steps involve closure of the dipolar biradical **4** to the tricyclic intermediate **5** followed by opening to **6**.

Perhaps the most important mechanistic result to date is the finding that the reaction with *cis*- and *trans*-2-butene is >95% stereospecific.[8] This result essentially limits the reaction to either a concerted $[2_\sigma + 2_\pi]$ cycloaddition through the dipolar intermediate **8** or an addition reaction through the biradical **7** in which rotation around the C–C bond is slower than closure resulting in retention of stereochemistry.

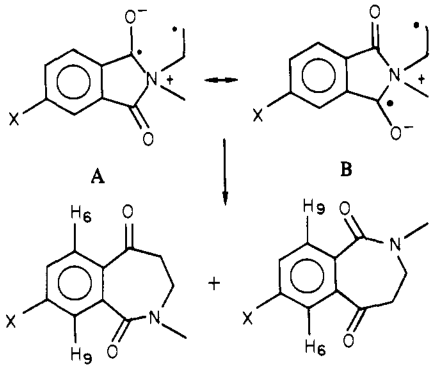


We wish to report the regioselective addition of alkenes to aryl-substituted phthalimides **10** in which the lack of symmetry makes the two C(O)–N bonds nonequivalent. Assuming that a biradical mechanism is operative, addition of an alkene to excited phthalimide should afford a ground-state dipolar biradical best described by canonical forms A and B. With respect to the electron distribution on the C–O bond, this intermediate could be viewed as a radical anion.[12]



10

a, X = OMe
b, X = CH_3
c, X = Cl
d, X = CO_2Me



With regard to the generation of radical anions it is known from electrochemical studies that para substitution by acceptor groups enhances reduction of carbonyl groups, and donors disfavor this reaction.[13,14] Thus, one might expect canonical structure B to be favored by donors and A by acceptors and **11** and **12** to predominate with acceptor and donor substituents, respectively.

Evidence on this point derives from trapping of the radical anion–radical cation **13**, photochemically generated from **10** and 2,3-dimethyl-2-butene in methanol.[15] The major product from

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(1) For a recent review, see: Mazzocchi, P. H. *Org. Photochem.* **1981**, *5*, 421.

(2) Mazzocchi, P. H.; Bowen, M.; Narain, N. *J. Am. Chem. Soc.* **1977**, *99*, 7063.

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(5) Kanaoka, Y.; Yoshida,, K.; Hatanaka, Y. *J. Org. Chem.* **1979**, *44*, 664.

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(7) Mazzocchi, P. H.; Wilson, P., unpublished results.

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(10) Mazzocchi, P. H.; Minamikawa, S.; Wilson, P. *Tetrahedron Lett.* **1978**, 4361.

(11) Maruyama, K.; Kubo, Y. *Chem. Lett.* **1978**, 851.

(12) If one evaluates the canonical structure A and B in terms of the radical stabilizing effects of substituents, then it might be expected that A would be most stable since virtually all substituents stabilize radicals. In this case, the same product should predominate in all the substituted cases.

(13) Zuman, P. "Substituent Effects in Polarography"; Plenum Press: New York, 1967; p 43-129.

(14) (a) Bartel, E. T.; Grabowski, Z. R. *Pr. Konf. Polarogr.* **1956**, 323. (b) Holleck, L.; Marsen, H. *Z. Electrochem.* **1953**, *57*, 944.

(15) We have demonstrated[10] that alkenes of high oxidation potential undergo addition whereas those with low oxidation potentials efficiently electron transfer. Similar results have also been obtained by Maruyama and Kubo.[11]

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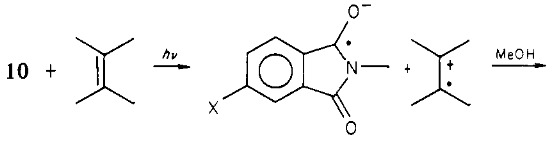
Table I. Product Distribution from Photolysis of **10**

10	X = OMe	X = CH_3	X = Cl	X = CO_2Me
% **11**	100	57	52	27
% **12**	0	43	48	73
% yield (**11** and **12**)	32	32	45	46

this reaction with a strong donor substituent (**10**, X = OCH_3) is **14a** (66:34 **14a**–**14b**), whereas with a strong acceptor (**10**, X = CO_2Me) the only product isolated is **15**.[16]



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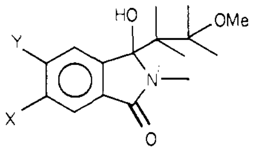
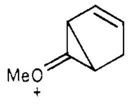


14a, X = H; Y = OCH_3
b, X = OCH_3; Y = H
15, X = CO_2Me; Y = H

In a concerted process, the product distribution should reflect the excited-state C–N double-bond character or excitation localization induced by the substituent. Although we have shown that the reaction proceeds via the singlet state,[17] we are unable to completely assess the nature of the reactive excited state at present. The application of excited-state criteria previously developed[19] predicts that donors direct incoming electrophiles meta in photochemical reactions. Incorporation of this model into the methoxyphthalimide system suggest that [2 + 2] addition of an alkene should occur at the position of maximum N–C double-bond character, i.e., bond a in **17**. Acceptor substituents should direct the incoming reactant to bond b. Irrespective of these arguments, we expect donor and acceptor substituents to have opposite effects, as they do in other photochemical reactions,[19] and result in different regiochemistry.



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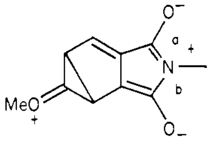

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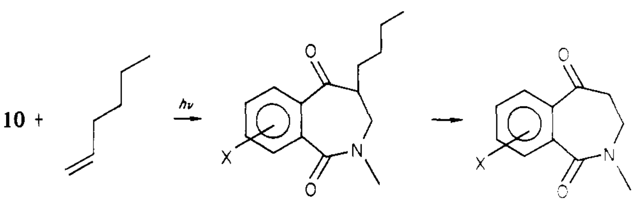
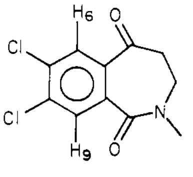
A series of substituted phthalimides **10** (X = OCH_3, CH_3, Cl, CO_2Me) were irradiated in the presence of 1-hexene in acetonitrile, and the products **19**, which result from a type II process on the initially formed products **18**,[1,9] were isolated. Structure proof for the two regioisomers **11** and **12** was provided by analysis of the aromatic region of the proton NMR spectrum of **20**, **21a**, and **21b**.[20] The spectrum of **20** shows the aromatic protons as singlets at δ 8.01 and 7.76 indicating that there are dramatic differences in the deshielding effects of the ketone and lactam moieties on the peri hydrogens. Our original assignment of the most downfield-shifted proton in **20** to H_6 was confirmed by examination of the spectrum of **21a** which showed the peri hydrogen (H_p) as a doublet of doublets at δ 7.72, whereas in **21b** this proton was part of the complex aromatic multiplet at δ 7.36–6.96.



18 **19**



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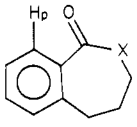

21a, X = CH_2
b, X = NH

The structures of the photolysis products **11** and **12** follow from analysis of the coupling patterns of their most downfield-shifted protons. For example, the NMR spectrum of **11c** shows H_6 as a doublet (J = 8 Hz) at δ 7.88, whereas, for **12c** H_6 appears as a doublet (J = 2 Hz, meta coupling) at δ 7.88. Similar analysis gave the structures of the other **11**, **12** isomers.

The product distribution (Table I) is clearly inconsistent with the results of our radical anion trapping studies but in accord with our ad hoc prediction for a concerted reaction. Although we favor a concerted process for this reaction on the basis of these results and those of our stereochemical studies,[9] the possibility that the reaction might occur through an oriented exciplex which rapidly decays through a biradical (A ↔ B) to the product cannot be discounted completely.

Acknowledgment. We thank the National Science Foundation for their generous support.

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[16] Mazzocchi, P. H.; Khachik, F. *Tetrahedron Lett.*, in press.

[17] Recent quenching studies on the intramolecular photoaddition of *N*-pentenylphthalimide, using 2,3-dimethyl-2-butene as an electron-transfer quencher, have resulted in the determination of a k_r for this reaction of $\sim 10^8$. Since the phosphorescence lifetime is ~1 s for *N*-propylphthalimide,[18] we conclude that the addition reaction proceeds via the singlet.[7]

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[20] Substituted phthalimides were synthesized by conventional methods. Isomeric benzazepinedione products were isolated by semipreparative HPLC on silica gel using ether–hexane as eluant. All new compounds gave acceptable IR, NMR, and analytical data. Details will be presented in a full paper on the subject.

Infrared Spectra of Gas-Phase Ions and Their Use in Elucidating Reaction Mechanisms. Identification of $C_7H_7^-$ Structural Isomers by Multiphoton Electron Detachment Using a Low-Power Infrared Laser

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The ability to distinguish structural isomers of ions on the basis of their vibrational spectra is of considerable interest since a general method would greatly extend the capabilities of mass spectrometry. It is difficult to achieve number densities of gas-phase ions sufficient to observe infrared absorption directly,[1-4] so indirect methods have been developed by inducing unimolecular[5] or modified bimolecular[6] reactivity as a result of absorption of one

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[3] Infrared chemiluminescence has been observed from neutral products of ion-molecule reactions[4] and more recently from ionic products as well (Bierbaum, V., private communication).

[4] Zwier, T. S.; Bierbaum, V. M.; Ellison, G. B.; Leone, S. R. *J. Chem. Phys.* **1980**, *72*, 5426–5436.

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