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IRRELEVANCE OF AZIDE TRAPPING TO MECHANISM OF THE ENE REACTION[1]

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The addition of singlet oxygen to olefins to produce allylic hydroperoxides is formally analogous to the Alder "Ene" reaction.[2] A concerted, cyclic mechanism, originally proposed by Nickon,[3] has been accepted by many workers on the basis of the clean shift of the double bond to the allylic position, the cis relationship between the entering oxygen and the transferred hydrogen, the lack of Markovnikov or substituent effect on product distribution, and the lack of solvent effect on the rate.[2,4] These arguments make unlikely but do not conclusively rule out a mechanism (originally suggested by Sharp)[5] involving an intermediate "perepoxide" (1) which opens to product.
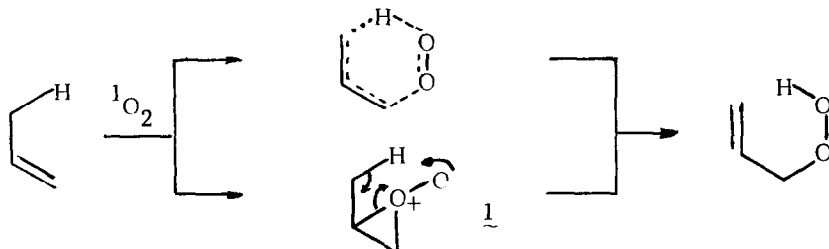
Recently, the perepoxide mechanism was given support by the observation that added $1\underline{M}$ NaN$_3$ diverts most of the products of photooxygenation of several olefins to azidohydroperoxides (2). These new products were interpreted as being formed from the perepoxide by nucleophilic reaction with azide ion.[6*]
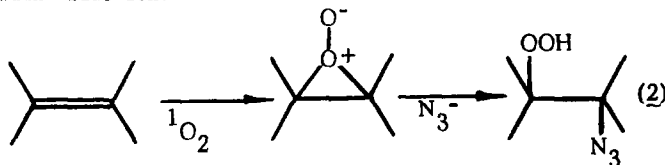
We now present evidence that azidohydroperoxides are formed in a reaction which competes with but is distinct from the normal oxygenation, and that no intermediate formed from singlet oxygen and the olefin is common to both reactions. This conclusion is based on several types of

*The original suggestion that a 1,2-dioxetane was the intermediate[7] has been ruled out by the observation that some dioxetanes do not give allylic hydroperoxides, but cleave to carbonyl products.[8]

evidence. 1) The ratio of normal products to azidohydroperoxides is strongly dependent on sensitizer type and concentration; dyes which are very poor sensitizers for normal photooxygenations produce the largest relative amount of azidohydroperoxide. 2) NaN_3 strongly quenches singlet oxygen; the reaction does not obey the kinetics for the perepoxide trapping scheme. 3) Dimethylfuran competitively inhibits the formation of ene products much more than the formation of azidohydroperoxides. 4) Azidohydroperoxides can be formed in a free radical reaction.

    1. <u>Sensitizer dependence</u>. 2-Methyl-2-pentene was photooxidized with NaN_3 in the presence of various dyes in 12% aq. CH_3OH. The amounts of allylic hydroperoxides (AO_2) and azidohydroperoxides (AO_2HN_3) formed in 4 hours irradiation were determined gas chromatographically (internal standard) after reduction with $NaBH_4$ (Table 1). Controls for the stability of products were carried out; AO_2 amounts are corrected for traces which were present in starting olefin.
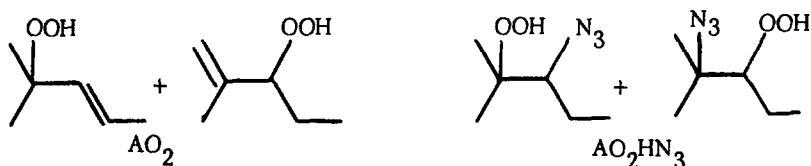

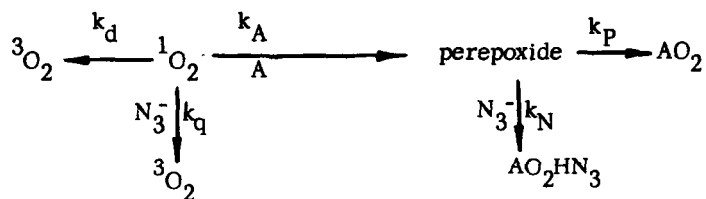Table 1. Products of Photooxygenation of 0.1$\underline{M}$ 2-Methyl-2-Pentene with 0.1$\underline{M}$ NaN_3.

Sensitizer($5\times10^{-5}\underline{M}$)	Products ($\times 10^3$ mMol) AO_2	AO_2HN_3	$\dfrac{AO_2HN_3}{AO_2}$	% tertiary O AO_2	AO_2HN_3
Rose Bengal	19.5	1.44	0.074	49	95
Erythrosin	19.5	2.27	0.117	48	96
Methylene Blue	1.50	7.89	5.36	67	94
Eosin B	0.50	2.76	5.48	57	95
Rhodamine B	1.10	9.29	8.44	55	94
Acridine Orange	0.29	2.13	7.37	81	94
Crystal Violet	0.10	0.89	8.32	85	96

    From table 1 it is clear that: 1) there is no correlation between AO_2 and AO_2HN_3 production with different sensitizers. 2) Rhodamine B and Crystal Violet (which are very poor sensitizers for photooxygenation because both have very poor yields of intersystem crossing[9]) give the highest AO_2HN_3/AO_2 ratio; 3) those sensitizers which give high AO_2HN_3/AO_2 ratios also give more tertiary AO_2 than normal for the photooxygenation reaction; this observation suggests that with these sensitizers some or all of the AO_2 may be produced via a non-singlet oxygen mechanism.

    With Rhodamine B, the amount of AO_2 did not increase above $10^{-3}\underline{M}$ dye, but the amount of AO_2NH_3 increased continuously, even at concentrations far greater than sufficient to absorb all light. <u>These observations suggest that the dye is directly involved in the formation of AO_2HN_3</u>.

    2. <u>Kinetics</u>. Sodium azide strongly quenches $^1O_2$, as shown by a series of experiments in which 2-methyl-2-pentene (A) photooxygenation was studied with varying amounts of azide; the variation of AO_2 production with [A] at different N_3^- concentrations is shown in Fig. 1. The

increase in slope of these plots with no change in intercept is diagnostic for singlet oxygen quenching.[10] If $^1O_2$ quenching is included as a separate step, the proposed perepoxide mechanism becomes:

$$^3O_2 \xleftarrow{k_d} {}^1O_2 \cdot \xrightarrow[A]{k_A} \text{perepoxide} \xrightarrow{k_P} AO_2$$

$$N_3^- \Big\downarrow k_q \qquad\qquad N_3^- \Big\downarrow k_N$$

$$^3O_2 \qquad\qquad\qquad AO_2HN_3$$

which yields the following expressions:

$$[AO_2]^{-1} = \text{Const}\left(\frac{k_d}{k_A[A]} + \frac{k_q[N_3^-]}{k_A[A]} + 1\right)\left(1 + \frac{k_N[N_3^-]}{k_P}\right)$$

$$[AO_2HN_3]^{-1} = \text{Const}\left(\frac{k_d}{k_A[A]} + \frac{k_q[N_3^-]}{k_A[A]} + 1\right)\left(1 + \frac{k_P}{k_N[N_3^-]}\right)$$

With this scheme, the ratio of slope to intercept of plots of both $[AO_2]^{-1}$ and $[AO_2HN_3]^{-1}$ vs. $[A]^{-1}$ must be identical, and equal to $(k_d + k_q[N_3^-])/k_A$. These plots are shown in Fig.2; the ratio of slope/intercept (1.5 for AO_2 and 8×10^{-3} for AO_2HN_3) differs by more than 200. Obviously the kinetic scheme cannot be correct. Fig.2 also shows that the production of excess tertiary AO_2 accompanies high AO_2HN_3/AO_2 ratios, as in Table 1.
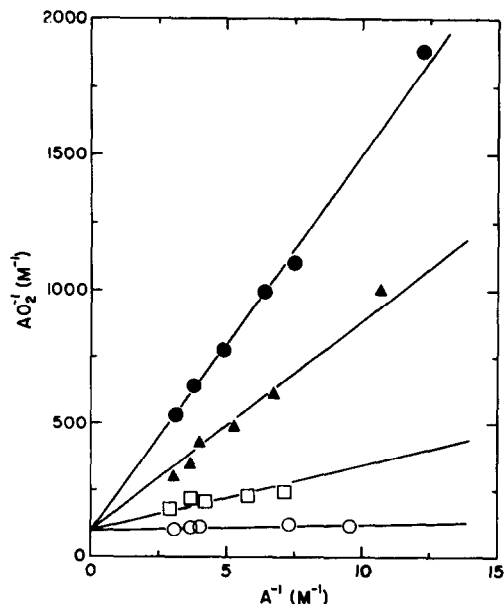

Fig.1. NaN$_3$ Quenching of Photooxygenation of A,CH$_3$OH:H$_2$O(85:15),10^{-4}M Methylene Blue.◯, N$_3^-$= 0;▢, 5x10^{-3}M; ▲, 10^{-2}M;●, 5 x 10^{-2}M.
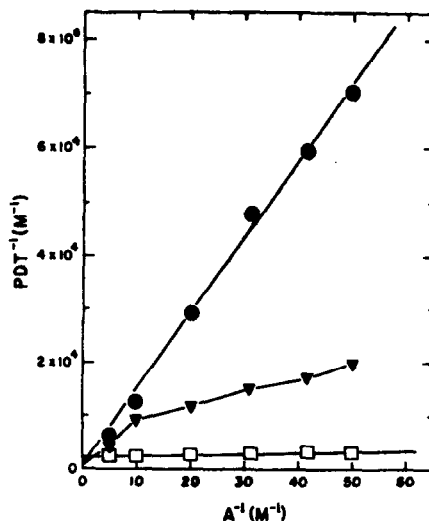
Fig.2. Product Dependance of Photooxygenation of A on [A].▢ , AO$_2$N$_3$H;▼ , tertiary AO$_2$;● , secondary AO$_2$.

3. <u>Competitive inhibition</u>. When sensitized photooxygenation of 2-methyl-2-pentene is carried out in the presence of NaN_3, both AO_2 and AO_2HN_3 should be subject to identical inhibition by the singlet oxygen acceptor dimethylfuran (DMF), if both are formed from singlet oxygen. The production of AO_2 is inhibited by more than 40-fold, but AO_2HN_3 production is inhibited only by a factor of 2.4, and the two products must be formed from different intermediates.

Table 2. Rhodamine B-Sensitized Photooxygenation of 2-Methyl-2-Pentene (0.125<u>M</u>) with 0.05<u>M</u> NaN_3 in 12.5% aq. CH_3OH with added DMF.

DMF,<u>M</u>	Products, <u>M</u>	
	sec - AO_2	AO_2HN_3
0.0	8.7×10^{-4}	4.5×10^{-3}
0.125	$\leq 2.1 \times 10^{-5}$	1.8×10^{-3}

4. <u>Formation of Azidohydroperoxides</u>. When NaN_3, iron sulfates, olefin, and H_2O_2 react, azidohydroperoxides are formed in an apparent free radical reaction.[11] When this reaction was carried out with 2-methyl-2-pentene the product mixture (12%) (by vpc after $NaBH_4$ reduction) was 2,3-diazido-2-methyl-pentane (48%), and the tertiary-OH (45%) and the secondary-OH (7%) azidoalcohols. Of the mixture, the 3° is 87%, compared to 95% in the photooxygenation (Tab.1). It seems likely that the azidohydroperoxides in the photooxygenation mixture may also arise by a free radical mechanism. The results of these studies show that AO_2 and AO_2HN_3 are formed by different mechanisms, and the azide product may not involve singlet oxygen at all. While the actual mechanism of formation of azidohydroperoxides is not completely established, it is clear that the path has nothing to do with the mechanism of the ene reaction. We continue to regard the cyclic mechanism for the ene reaction as the simplest consistent with the known facts.

<div align="center">References</div>

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