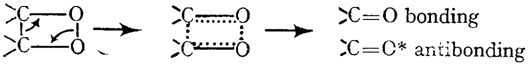
An Application of the Theory of Electrocyclic Reactions to Bioluminescence

By FRANK MCCAPRA

(*The Chemical Laboratory, University of Sussex, Brighton* BN1 9QJ)

WITH the elucidation of the structures of firefly (*Photinus pyralis*)[1] and *Cypridina hilgendorfii* luciferins,[2] and a partial structure for a third,[3] it has recently become possible to treat bioluminescence in terms of the more easily studied chemiluminescence of organic compounds. A probable general mechanism[4,5] for this latter type of reaction, involving the formation of a reactive four-membered peroxide ring, has allowed the successful prediction of chemiluminescence[5,6] and has been applied[6–8] to the cases of bioluminescence above.

Although the decomposition of the intermediate peroxide is highly exothermic, no suggestion has been advanced as to why an *electronically* excited product is formed. If we postulate that the decomposition is concerted, it can be shown† that conservation of orbital symmetry[9] in the formation of the carbonyl products necessarily results in an excited state of one of these groupings. Redistribution of this energy within the fluorescent product as a whole will lead to light emission. Alternatively, the transition state (see Figure) can be considered to be anti-aromatic ($4n$ electrons) and is thus likely to involve electronic excitation.[10] It is significant that, including strain energy, even the formation of the excited state is exothermic, thus perhaps accounting for the observation of a normally "forbidden" thermal route.



FIGURE

Other processes are no doubt possible in peroxide decompositions giving rise to chemiluminescence,

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† A detailed discussion and further evidence for the four-membered ring intermediate are the subjects of a forthcoming publication.

but the majority of easily visible examples, including acridinium salts,[5,11] indolyl peroxides,[6] oxalate phenyl esters,[12] diphenylcarbene,[13] tetrakisdimethylaminoethylene,[14] lucigenin[11a,15] and substituted imidazoles,[16] as well as the luciferins, may fit this scheme.

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[1] E. H. White, F. McCapra, G. F. Field, and W. D. McElroy, *J. Amer. Chem. Soc.*, 1961, **83**, 2402; E. H. White, F. McCapra, and G. F. Field, *ibid.*, 1963, **85**, 337.

[2] Y. Kishi, T. Goto, Y. Hirata, O. Shimomura, and F. H. Johnson, *Tetrahedron Letters*, 1966, 3427.

[3] K. Hori and M. J. Cormier, *Biochim. Biophys. Acta*, 1966, **130**, 420.

[4] F. McCapra and D. G. Richardson, *Tetrahedron Letters*, 1964, 3167.

[5] F. McCapra, D. G. Richardson, and Y. C. Chang, *Photochem. and Photobiol.*, 1965, **4**, 1111.

[6] F. McCapra and Y. C. Chang, *Chem. Comm.*, 1966, 522.

[7] F. McCapra and Y. C. Chang, *Chem. Comm.*, 1967, 1011.

[8] F. McCapra, Y. C. Chang, and V. P. Francois, *Chem. Comm.*, 1968, 22.

[9] R. B. Woodward, "Aromaticity," *Chem. Soc. Special Publ.* No. 21, 1967, 217, and references cited.

[10] M. J. S. Dewar, ref. 9, p. 177, and references cited.

[11] (a) F. McCapra, *Quart. Rev.*, 1966, **20**, 485; (b) M. M. Rauhut, D. Sheehan, R. A. Clarke, B. G. Roberts, and A. M. Semsel, *J. Org. Chem.*, 1965, **30**, 3587.

[12] L. J. Bollyky, M. Loy, B. Roberts, R. H. Whitman, A. V. Iannotta, A. M. Semsel and M. M. Rauhut, American Chemical Society, 153rd Meeting Abstracts, 1967, 0–169. These authors propose, and have evidence for a four-membered peroxide ring.

[13] A. M. Trozzolo, R. W. Murray, and E. Wasserman, *J. Amer. Chem. Soc.*, 1962, **84**, 4991.

[14] A. N. Fletcher and C. A. Heller, *J. Phys. Chem.*, 1967, **71**, 1507; W. H. Urry and J. Sheeto, *Photochem. and Photobiol.*, 1965, **4**, 1067.

[15] J. R. Totter and G. E. Philbrook, *Photochem. and Photobiol.*, 1966, **5**, 177.

[16] E. H. White and M. J. C. Harding, *Photochem. and Photobiol.*, 1965, **4**, 1129. A four-membered peroxide ring is suggested and discussed by these workers also.