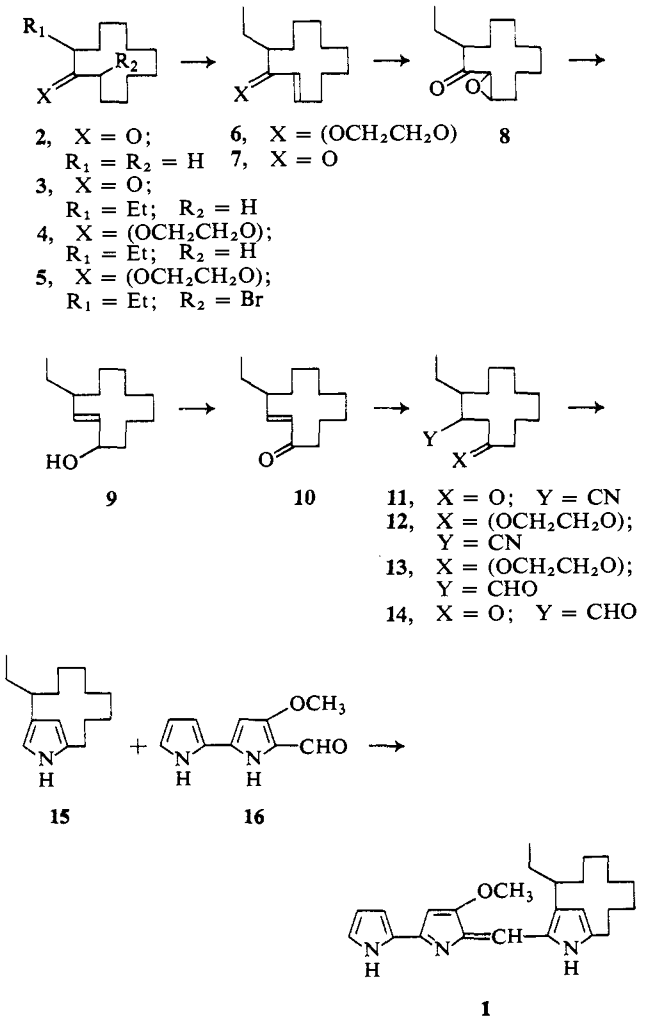

2, X = O; R1 = R2 = H
3, X = O; R1 = Et; R2 = H
4, X = (OCH2CH2O); R1 = Et; R2 = H
5, X = (OCH2CH2O); R1 = Et; R2 = Br
6, X = (OCH2CH2O)
7, X = O
8
9
10
11, X = O; Y = CN
12, X = (OCH2CH2O); Y = CN
13, X = (OCH2CH2O); Y = CHO
14, X = O; Y = CHO
15
16
1

60°. The α,β-epoxy ketone mixture **8**, upon treatment with 85% aqueous hydrazine hydrate and a catalytic amount of HOAC in EtOH for 12 hr at 25°,[8] yielded 4-ethyl-2-cyclododecenol (**9**)[3] (33%): bp 97–100° (0.1 mm); $\nu_{\max}^{\mathrm{CCl_4}}$ 3636, 3490, 1695, 980 cm^{-1}; $\tau_{\mathrm{CCl_4}}$ 4.73 (m, 2 H, -C*H*=C*H*-), 6.08 (broad absorption, 1 H, C*H*OH), 8.23 (s, 1 H, O*H*).[9] Oxidation[11] of the allylic alcohol **9** (sodium dichromate in sulfuric acid) produced 4-ethyl-2-cyclododecenone (**10**)[3] (92%); $\lambda_{\max}^{\mathrm{EtOH}}$ 231 mμ (ε 11,200); $\lambda_{\max}^{\mathrm{CCl_4}}$ 1694, 1664, 1625, 994 cm^{-1}; $\tau_{\mathrm{CCl_4}}$ 3.7 (m, 2 H).

Reaction of **10** with KCN-NH_4Cl in 1:10 H_2O-DMF at 105° for 18 hr[12] yielded 3-cyano-4-ethylcyclododecanone (**11**) (42%): bp 113–116° (0.5 mm); $\nu_{\max}^{\mathrm{CCl_4}}$ 2240 cm^{-1}; $\tau_{\mathrm{CCl_4}}$ 6.5–8.0 (m, 5 H). Ketalization of **11** (ethylene glycol) gave the cyano ketal **12**[3] (95%): $\nu_{\max}^{\mathrm{CCl_4}}$ 2240 cm^{-1}; $\tau_{\mathrm{CCl_4}}$ 6.07 (m, 4 H), 7.3 (m, 1 H). The nitrile **12** was reduced with diisobutylaluminum hydride[13] yielding the ketal aldehyde **13**[3] (95%): $\nu_{\max}^{\mathrm{CCl_4}}$ 2820, 2712, 1723 cm^{-1}; $\tau_{\mathrm{CCl_4}}$ 0.40 (m, 1 H), 6.20 (m, 4 H), 7.5 (m, 1 H). Hydrolysis of **13** followed by reaction of the resultant keto aldehyde **14** [$\nu_{\max}^{\mathrm{CCl_4}}$ 2830, 2722, 1724, 1710 cm^{-1}; $\tau_{\mathrm{CCl_4}}$ 0.23 (m, 1 H), 6.9 (m, 1 H), 7.35 (m, 2 H), 7.68 (m, 2 H)] with $(NH_4)_2CO_3$ in 1:6 H_2O-DMF[14] yielded the C-15 *dl*-metacyclopyrrole **15** (58%): bp 109–111° (0.2 mm); mp 59–61°. The synthetic pyrrole has ir, nmr, and mass spectra identical with those of the pyrrole obtained by pyrolysis of natural metacycloprodigiosin.[1]

Condensation of **15** with the known C-10 methoxybipyrrole precursor **16**[15–17] in ethanolic HCl at 25° for 24 hr afforded, after chromatography on basic alumina, *dl*-metacycloprodigiosin (**1**) (90%), mp 219–221°. The brilliant red pigment has uv, visible, ir, nmr, and mass spectra identical with those of the natural prodigiosin.[1]

Acknowledgments. We are indebted to Dr. Eugene Gosselink and Mr. Richard Sykes for their participation in valuable exploratory studies on the synthesis of *meta*-bridged pyrroles. Mass spectrometric analyses were determined by Dr. W. McMurray. We also thank Mr. Stuart Rosenfeld for technical assistance. Financial support was provided by National Institutes of Health Grant AI 04798.

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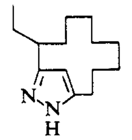
[9] The major product from this reaction was the pyrazole i.[10]



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[18] National Institutes of Health Predoctoral Fellow, 1966–1968.

The Mechanism of Direct *cis–trans* Photoisomerization of the Stilbenes. The Nature of the Azulene Effect

Sir:

The conclusion that intersystem crossing does not lie in the path leading to *cis–trans* photoisomerization of the stilbenes depends on the assumption that the azulene effect on the direct photoisomerization is due entirely to radiationless transfer of excitation from *trans*-stilbene singlets, ^1t, to azulene (eq 1).[1] The much larger azulene effect obtained under triplet (sensitized) excitation conditions

$$^1t + {}^0\mathrm{Az} \xrightarrow{k_1} {}^0t + {}^1\mathrm{Az} \qquad (1)$$

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[1] J. Saltiel, E. D. Megarity, and K. G. Kneipp, *J. Am. Chem. Soc.*, **88**, 2336 (1966).

Table I. Azulene Effect on Stilbene Photoisomerization[a]

Solvent	η[b], cP	Sensitizer[c]	$k_2/\alpha k_7 K_6$, M^{-1}	$k_1/(k_F + k_4)$, M^{-1}
Benzene	0.564	Benzophenone	130[8]	
Benzene	0.564	None		14.$_0$
n-Pentane	0.220	Fluorenone	237	
n-Pentane	0.220	None		14.$_2$

[a] Experiments at 30°. [b] Viscosities from data in "Handbook of Chemistry," N. A. Lange, Ed., 9th ed, Handbook Publishers Inc., Sandusky, Ohio, 1956, pp 1658, 1660. [c] The azulene effect is not sensitizer dependent.[2]

has been attributed to excitation transfer from *trans*-stilbene triplets, ^3t (eq 2).[2] This interpretation of the azulene effect has not been generally accepted, and recent

$$^3t + {}^0\mathrm{Az} \xrightarrow{k_2} {}^0t + {}^3\mathrm{Az} \qquad (2)$$

discussions of the direct photoisomerization of the stilbenes still favor intersystem crossing as a key step in the reaction.[3-7] In the following, results are presented which strongly support our interpretation of the azulene effect,[1] and thus the singlet mechanism for stilbene photoisomerization.[8]

According to the singlet mechanism major decay paths for ^1t are fluorescence, rotation about the central bond, and self-quenching (eq 3–5, respectively). The self-quenching step (5) is neglected for low concentrations of

$$^1t \xrightarrow{k_F} {}^0t + h\nu \qquad (3)$$

$$^1t \xrightarrow{k_4} {}^1\mathrm{p} \qquad (4)$$

$$^1t + {}^0t \xrightarrow{k_5} 2{}^0t \qquad (5)$$

trans-stilbene.[1,2] The rate of fluorescence, $k_F = 4 \times 10^8$ sec^{-1}, has been calculated from the $S^0 \rightarrow S^1$ absorption spectrum.[9] Since the fluorescence quantum yield of *trans*-stilbene at 30° is 0.08,[7,10] the actual lifetime of ^1t at 30° in the absence of azulene is $(k_F + k_4)^{-1} = 2 \times 10^{-10}$ sec. To compete with first-order decay from ^1t, singlet excitation transfer (eq 1) must occur over distances greater than normal collisional diameters, and its efficiency should be insensitive to changes in solvent viscosity.[11] On the other hand, triplet excitation transfer to azulene (eq 2) is expected to be diffusion controlled and should depend on solvent viscosity.[8]

The effect of azulene on photostationary states for the direct and sensitized photoisomerization of the stilbenes was determined in benzene and in *n*-pentane.[12] In each case stationary-state [*trans*]/[*cis*] ratios were linearly dependent on azulene concentration (linear correlation coefficients >0.99).[13] Slope/intercept ratios from the linear plots are interpreted in terms of rate constant ratios in Table I. Rate constants are defined in eq 1–7 where ^{1}p and ^{3}p are twisted S^1 and T^1 states, respectively.

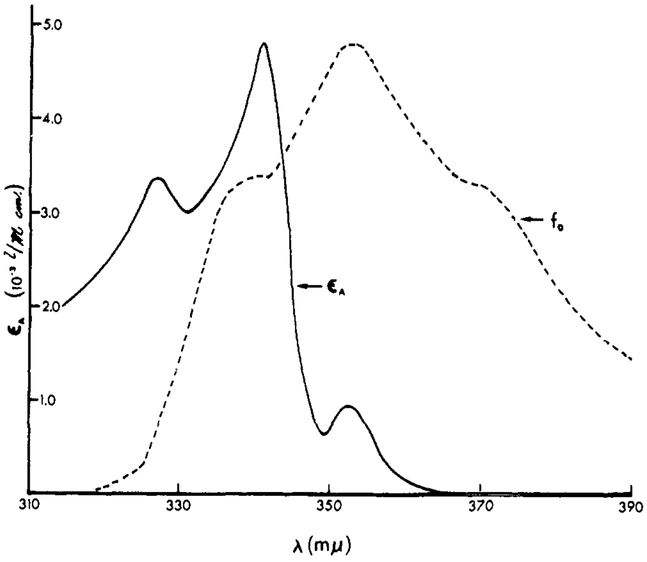

Figure 1. Spectral overlap between *trans*-stilbene fluorescence and azulene absorption.

$$^3t \underset{k_{-6}}{\overset{k_6}{\rightleftarrows}} {}^3\mathrm{p} \qquad (6)$$

$$^3\mathrm{p} \xrightarrow{k_7} \alpha{}^0t + (1 - \alpha){}^0c \qquad (7)$$

The results in Table I show that, whereas there is a sizable increase in the azulene effect on the sensitized photoisomerization when solvent viscosity is decreased, the effect of azulene on the direct photoisomerization is independent of solvent viscosity.[14] Were the formation of triplet states even partially responsible for the azulene effect of the direct photoisomerization some dependence of slope/intercept ratios on viscosity should have been observed.[16]

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(8) (a) J. Saltiel, *ibid.*, **89**, 1037 (1967); (b) *ibid.*, **90**, 6394 (1968).

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(12) Experimental methods have been described: 3130-Å light was used for direct irradiations and 3660-Å light for sensitized irradiations.[7,8] Analysis was by glpc.[8]

(13) The curvature found in the original determination of the azulene effect on the direct photoisomerization in benzene[2] is attributed to the larger experimental uncertainty in the initial experiments in which lower total stilbene concentrations were employed. Present results were for 0.01 *M* stilbene and were reproduced in independent experiments using two different 3130-Å filter trains.

(14) The increase in $k_2/\alpha k_7 K_6$[15] is not exactly proportional to η^{-1} as would be expected if k_2 were the only constant in the ratio which is viscosity dependent.[8] Unpublished observations in this laboratory suggest that the discrepancy is due to a change of $k_7 K_6$ and should not be interpreted as indicating that eq 2 is not entirely diffusion controlled. Preliminary fluorescence quantum yield measurements indicate that k_4 does not change within the viscosity range used.

(15) We thank one of the referees for pointing out that the equilibrium constant, K_6, was omitted in ref 8b. The term $k_7(1 - \beta)$ in eq 10 of ref 8b should be replaced with $k_7(1 - \beta)K_5$.

Theoretical expressions describing long-range singlet energy transfer have been derived by Förster.[11] For the case of weak coupling, R_0, the distance in centimeters at which the transfer rate equals the normal decay rate of the excited donor, is given by eq 8 where ϕ_D is the fluorescence

$$R_0 = \left(\frac{(8.79 \times 10^{-25})K^2\phi_D}{n^4}\int_0^\infty f_D(\tilde{\nu})\varepsilon_A(\tilde{\nu})\frac{d\tilde{\nu}}{\tilde{\nu}^4}\right)^{1/6} \qquad (8)$$

quantum yield of the donor, K^2 is an orientation factor (taken as $^2/_3$ for random distribution), n is the index of refraction of the solvent, f_D is the donor fluorescence spectrum normalized to unity, and ε_A is the acceptor molar decadic extinction coefficient. The integral in eq 8 is large when there is good spectral overlap between donor fluorescence and acceptor absorption. Figure 1 shows the spectral overlap between *trans*-stilbene fluorescence and azulene absorption. The calculated value of R_0 in benzene is 16 Å.[17] The experimental value of R_0 in ångströms is given approximately by eq 9.[18,19] Substitution

$$R_0 = 7.35\left(\frac{k_1}{k_F + k_4}\right)^{1/3} \qquad (9)$$

of the rate constant ratio from Table I in eq 9 gives 18 Å for R_0, in excellent agreement with the theoretical value.[21]

Our results show that eq 1 is responsible for the azulene effect on the direct photoisomerization of the stilbenes and that the triplet mechanism does not obtain.

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[16] We have observed such an effect with *p*-bromostilbene for which the triplet mechanism provides the minor path (20–35%) for the isomerization at 30°.

[17] We thank Dr. A. A. Lamola for the evaluation of the integral in eq 8.

[18] N. J. Turro, "Molecular Photochemistry," W. A. Benjamin, Inc., New York, N. Y., 1965, p 101.

[19] Dr. A. A. Lamola has informed us that a treatment which attempts to be exact gives 6.32 instead of 7.35 in eq 9.[20] With this substitution a value of 15 Å is calculated for the experimental R_0.

[20] R. Povinelli, Ph.D. Thesis, University of Notre Dame, 1964.

[21] Derivation of eq 8 is based on the assumption that R_0 is large compared to molecular dimensions. The close correspondence between the theoretical and experimental values of R_0 is interesting, since this assumption is marginal in this case.[22]

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[23] National Institutes of Health Predoctoral Research Fellow, 1965–present.

Book Reviews

Thermodynamics of Steady States. By Ralph J. Tykodi, Associate Professor of Chemistry, Southeastern Massachusetts Technological Institute. The Macmillan Co., 866 Third Ave., New York, N. Y. 1967. xvii + 217 pp. 16 × 24 cm. $10.95.

It is well known that scientists react strongly to thermodynamics. To some, its inner logic and economy of principle make it an esthetically satisfying and powerful tool; to others, it is merely useful and dull. Some thermodynamicists regard their subject as well founded on a few simple and obvious axioms; others (like myself) feel that the subject is not really complete without reference to its molecular foundation in statistical mechanics. Textbooks clearly reflect this difference in attitude.

Nonequilibrium thermodynamics seems to provoke much the same reactions. For those who feel most comfortable when statistical mechanical foundations are emphasized, the classic book by DeGroot and Mazur is still the best text on this subject. Those who prefer the axiomatic approach may find Tykodi's book appealing.

The author states his basic premises at the outset. In addition to the laws of ordinary thermodynamics, these can be paraphrased as follows: (1) nonequilibrium steady states can be maintained experimentally; (2) a nonequilibrium system can be divided into terminal parts and gradients, much in the way that electric networks can be treated as black boxes with inputs and outputs; (3) steady-state situations are governed by the principle of minimum entropy production; and (4) Onsager's reciprocal relations are valid. (Statistical mechanics tells us that premises 3 and 4 are correct for *linear* nonequilibrium processes. For nonlinear processes, it is still not clear what the appropriate generalizations are.)

From these principles, Tykodi analyzes many experimentally interesting situations involving steady flow of heat, radiant energy, electricity, and matter. Some examples are the various thermoelectric effects, thermal diffusion, concentration cells, etc. As in conventional thermodynamics, the language and notation are elaborate. A number of problems or exercises are presented; some are concerned with numbers, while others are in the fine old tradition of thermodynamic texts: "Derive Eqs. (8.15) and (8.16) from Eqs. (8.12) and (8.13)."

In conclusion, I feel that this book accomplishes successfully what the author claims in his preface: "This book does for the class of non-equilibrium situations and steady state processes what any good book on ordinary thermodynamics does for equilibrium situations; it develops a series of relations of interest in their own right; it helps the experimentalist plan his experiments efficiently by making use of the necessary interconnections among experimentally determined quantities; it provides the experimenter with some consistency checks on his measurements; and it yields equations interrelating macroscopic quantities—equations that are of use to engineers and that serve as guides for more detailed kinetic theory or statistical mechanical analysis of the phenomena." If you are satisfied with this minimal (though important) view of the subject, Tykodi's book will serve. If you want to know what is really going on in your nonequilibrium system, where the molecules are and what they are doing, you will have to go elsewhere.

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Amino Acid Determination. Methods and Techniques. By S. Blackburn, Wool Industries Research Association, Leeds, England. Marcel Dekker, Inc., 95 Madison Ave., New York, N. Y. 10016. 1968. xi + 271 pp. 16 × 23 cm. $12.50.

A student recently asked me to suggest a book which would give him a summary of the various parameters that have to be considered in the separation of amino acids by ion-exchange chromatography. Blackburn's monograph had just arrived and met this test fairly well.