Photodehydrocyclisation of 1-Styrylimidazoles; an HMO Study

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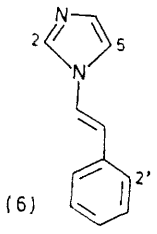
Photodehydrocyclisation of 4,5-diphenyl-1-styrylimidazole yields phenanthro[9′,10′:4,5]imidazo[2,1-*a*]isoquinoline *via* 1-styrylphenanthro[9,10-*d*]imidazole. Another possible intermediate, 2,3-diphenylimidazo[2,1-*a*]isoquinoline, undergoes photo-oxidation to yield 2-benzoyl-1-benzoylimino-1,2-dihydroisoquinoline. HMO calculations, in particular the resulting localisation energies, are a useful guide for predicting the mode of photocyclisation of 1-styrylimidazoles.

We have previously described the synthesis under mild conditions of 1-styrylimidazoles [1] and their stereospecific photodehydrocyclisation [2] to yield imidazo[2,1-*a*]isoquinolines. This reaction is related to the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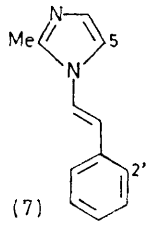
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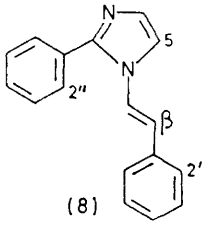
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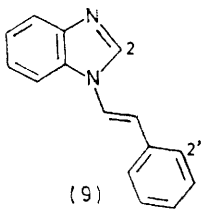
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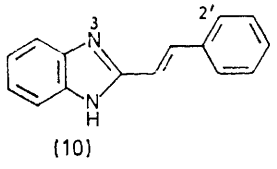
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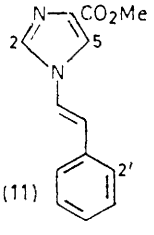
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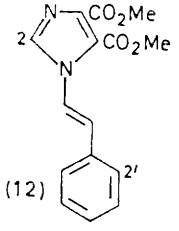
conversion of stilbene-like compounds into phenanthrene derivatives [3,4] for which qualitative rules to explain the ease and direction of cyclisation have been proposed. Simple Hückel molecular orbital (HMO) calculations [5] have been used [6,7] in attempts to rationalise photodehydrocyclisation reactions further. The sum of free valence indices in the excited state (ΣF^*), superdelocalisabilities (ΣS^*),[8] and localisation energies (L^*) have been found useful in predicting the course of cyclisation, and it appears that certain limiting values may operate.[7] Attempts to extend this parameterisation to rate processes,[9] however, appear to be less soundly based.[10] Although heterocyclic compounds have been considered in the above studies none of the reactions studied is comparable to the 1-styrylimidazole cyclisations. A postulated mechanism for the photodehydrocyclisation of *cis*-1-styrylimidazole (1) to imidazo[2,1-*a*]isoquinoline (3) is shown in Scheme 1. To enable dihydro-intermediates to be formed, dipolar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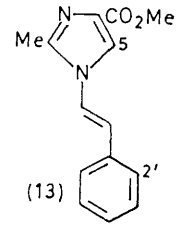
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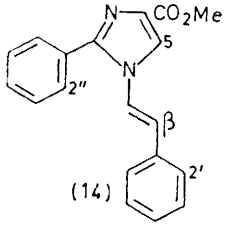
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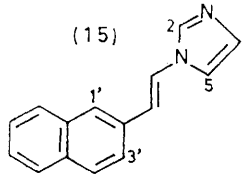
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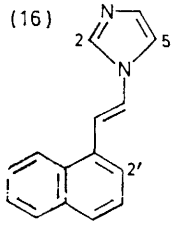

(16)

excited states similar to those considered for simple imidazoles [11] must be postulated, and it appears that in this case the stereospecificity depends upon the relative stabilities of the dihydro-intermediates (2) and (4). In an attempt to study the factors which control the mode

[1] G. Cooper and W. J. Irwin, *J.C.S. Perkin I*, 1975, 798; 1976, 545.

[2] G. Cooper and W. J. Irwin, *J.C.S. Perkin I*, 1976, 75.

[3] R. M. Kellog, M. B. Groen, and H. Wynberg, *J. Org. Chem.*, 1967, **32**, 3093.

[4] H. H. PerKampus and G. Kassefier, *Annalen*, 1966, **696**, 1.

[5] A. Streitwiser, jun., 'Molecular Orbital Theory for Organic Chemists,' Wiley, New York, 1961; J. D. Roberts, 'Notes on Molecular Orbital Calculations,' Benjamin, New York, 1961; W. B. Smith, 'Molecular Orbital Methods in Organic Chemistry; H.M.O. and P.M.O.' Dekker, New York, 1974.

[6] M. Scholz, M. Muhlstadt, and F. Dietz, *Tetrahedron Letters*, 1967, 665.

[7] W. H. Laarhoven, Th. J. H. M. Cuppen, and R. F. J. Nivard, (*a*) *Rec. Trav. chim.*, 1968, **87**, 687; (*b*) *Tetrahedron*, 1970, **26**, 1069; (*c*) *ibid.*, p. 4865.

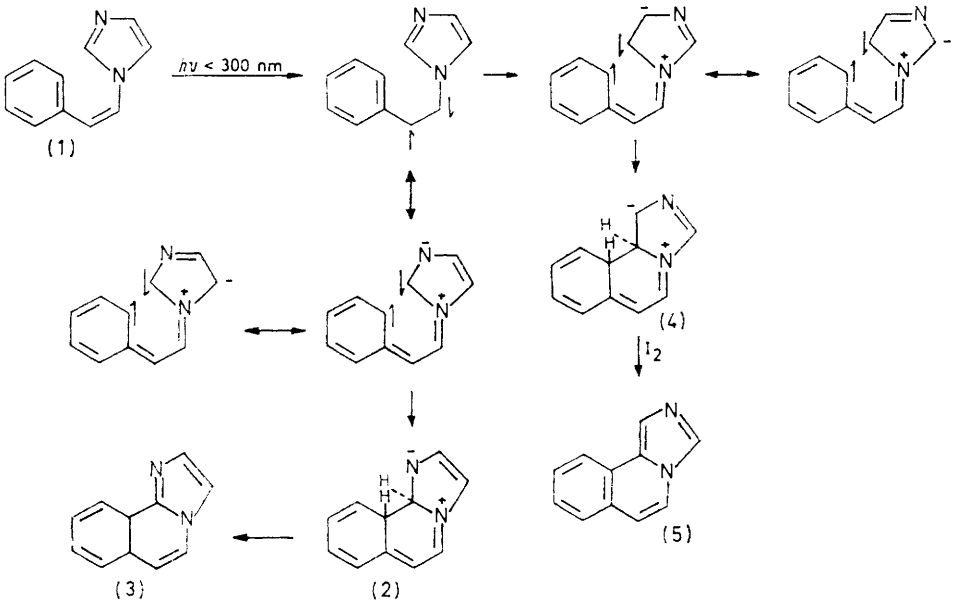
[8] K. Fukui, T. Yonezawa, and C. Nagata, *Bull. Chem. Soc. Japan*, 1954, **27**, 423.

[9] H. H. Perkampus and Th. Bluhm, *Tetrahedron*, 1972, **28**, 2099.

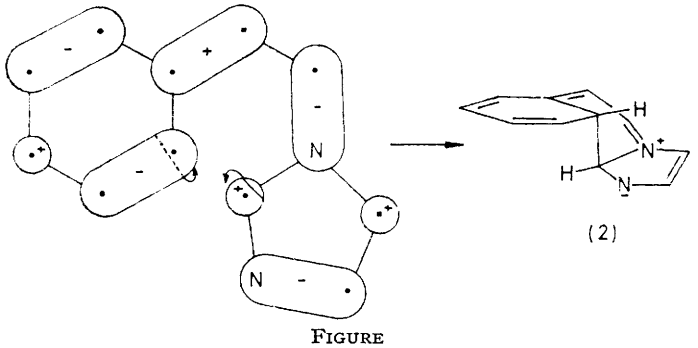
[10] D. D. Morgan, S. W. Morgan, and M. Orchin, *Tetrahedron Letters*, 1972, 1789.

[11] G. Leandri, A. Mangini, F. Montanari, and R. Passerini, *Gazzetta*, 1955, **85**, 769.

of cyclisation, and to examine the applicability of the above parameters to this non-alternant system in order to rationalise the selective mode of photocyclisation undergone by these compounds, we have undertaken HMO calculations on some 1-styrylimidazoles [(6)—(16) and (41)—(44)] and the corresponding dihydro-intermediates.



SCHEME 1



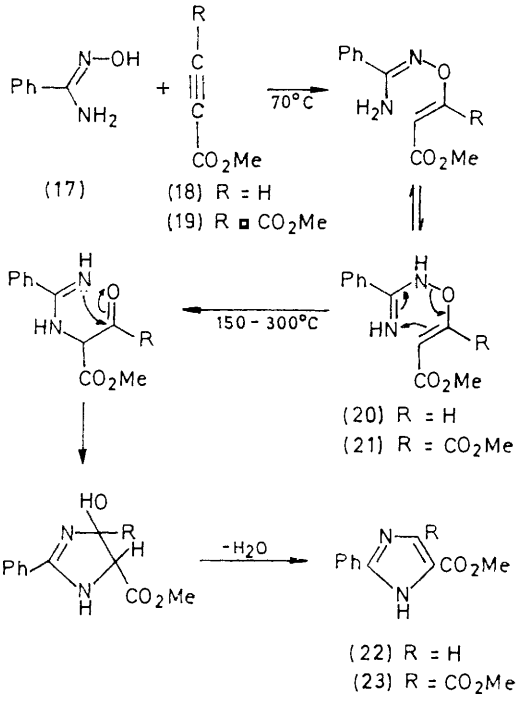
FIGURE

Synthetic Aspects.—The synthesis of dimethyl 2-phenylimidazole-4,5-dicarboxylate [12] (23) was attempted by an extension of a synthesis [13] of methyl 2-phenylimidazole-4(5)-carboxylate (22) *via* the reaction of benzamide oxime (17) with methyl prop-2-ynoate (18). It was thought that the use of dimethyl but-2-ynedioate (19) in this reaction could yield the required diester (23), and the intermediate addition compound (21) was formed, in good yield, from the acetylene (19) and benzamide oxime (17). The n.m.r. spectrum showed two singlets, in the ratio 6 : 1, at τ 4.04 and 4.19 [13,14] due to the *cis*- and *trans*-isomers respectively of the product (21). Rearrangement of the adduct proceeded readily at 150 °C (in diethylene glycol dimethyl ether) to give the same product as was obtained at 270 °C (in diphenyl ether). The mass spectrum of this product showed a molecular ion at *m/e* 246 rather than the expected value (*m/e* 260). The n.m.r. and i.r. spectra were also consistent with the conclusion that methanol, not water, had been eliminated in the final cyclisation step to form either the imidazole (24) or the pyrimidone (25).

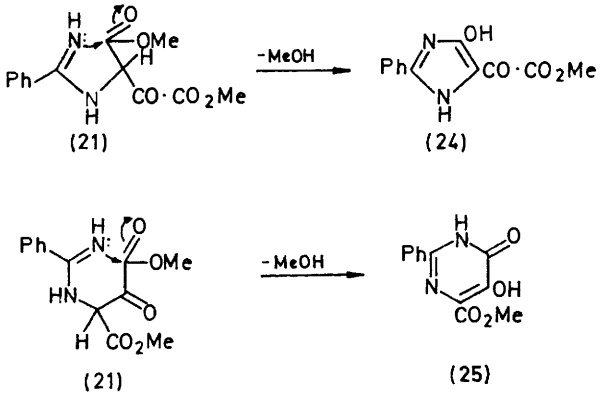
The ease with which the final cyclisation step, to yield any of the three possible products, occurs depends on two opposing factors: the relative reactivity of the carbonyl groups involved and the size of the ring formed. The pyrimidine (25) is formed *via* a six-membered transition state and is thus the most likely product. This conclusion was confirmed by degradation to the known pyrimidone (28) [15] by hydrolysis and decarboxylation.[16] It is known that 2- and 4-hydroxypyrimidines exist predominantly as the keto-tautomer, and it was suggested,[15] in the light of the chemical

[12] R. G. Fargher and F. L. Pyman, *J. Chem. Soc.*, 1919, **115**, 217.
[13] N. D. Heindel, *Tetrahedron Letters*, 1970, 25.
[14] T. Sheradsky, *Tetrahedron Letters*, 1970, 25.
[15] D. E. O'Brien, L. T. Weinstock, R. H. Springer, and C. C. Cheng, *J. Heterocyclic Chem.*, 1967, **4**, 49.
[16] F. Krohnka, E. Schmidt, and W. Zecher, *Chem. Ber.*, 1964, **97**, 1163.

properties of the pyrimidone (28), that the predominant structure was a diketo-tautomer (29). However, the

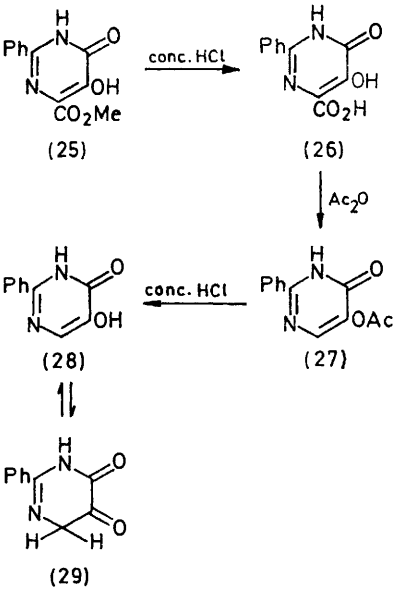


i.r. spectrum shows an O–H stretching vibration at 3 450 cm^{-1} and the n.m.r. spectrum exhibited a one-proton low field singlet at τ 2.39 assigned to H-6. It was



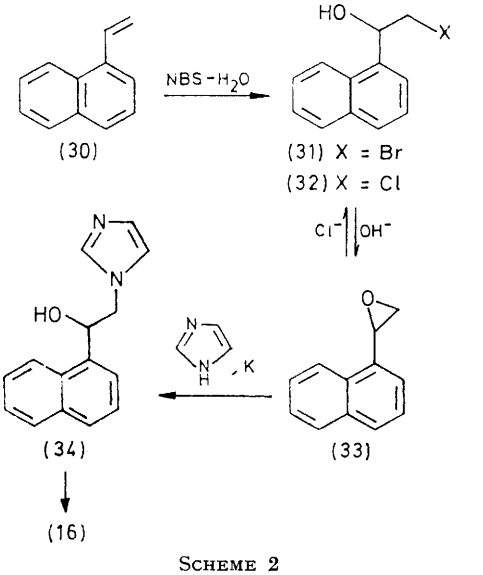
therefore concluded that the pyrimidone exists predominantly as the keto-tautomer (28).

We envisaged the partial synthesis of an aza-steroid system *via* photodehydrocyclisation of *trans*-1-(imidazol-1-yl)-2-(1-naphthyl)ethylene (16) to give the aromatic structure (35). Scheme 2 depicts the expected course of the reactions attempted during the synthesis of the olefin (16). The synthesis of the epoxide (33) from the olefin (30) was achieved by the method described for styrene oxide.[17] The reaction of the epoxide with imidazole, however, yielded the chlorohydrin (32) a result which indicates that the epoxide (33) is susceptible to nucleophilic ring opening under acidic but not basic conditions. 2-Naphthylethylene oxide may be more susceptible to attack by a bulky nucleophile under strongly basic conditions and would therefore be expected to lead to *trans*-1-(imidazol-1-yl)-2-(2-naphthyl)-ethylene (36) which might undergo photodehydrocyclisation. However, the product isolated was a mixture of 2-naphthylacetaldehyde and methyl 2-naphthyl ketone. The base-catalysed rearrangement of



epoxides to aldehydes and ketones has been well documented.[18]

The photodehydrocyclisation of the stilbene ⟶ phenanthrene type has been extended to include



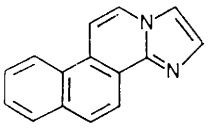
SCHEME 2

molecules in which the ethylenic moiety is part of an aromatic or heteroaromatic ring. A typical example of

[17] G. Cooper and W. J. Irwin, *J.C.S. Perkin I*, 1973, 911.

[18] A. Rosowsky, 'Heterocyclic Compounds with Three- and Four-membered Rings,' ed. A. Weissberger, Interscience, New York, 1964.

interest is the cyclisation [19] of 4,5-diphenylimidazole to phenanthro[9,10-*d*]imidazole. This reaction has also



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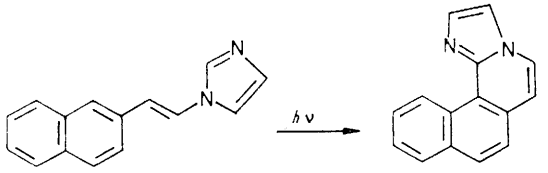


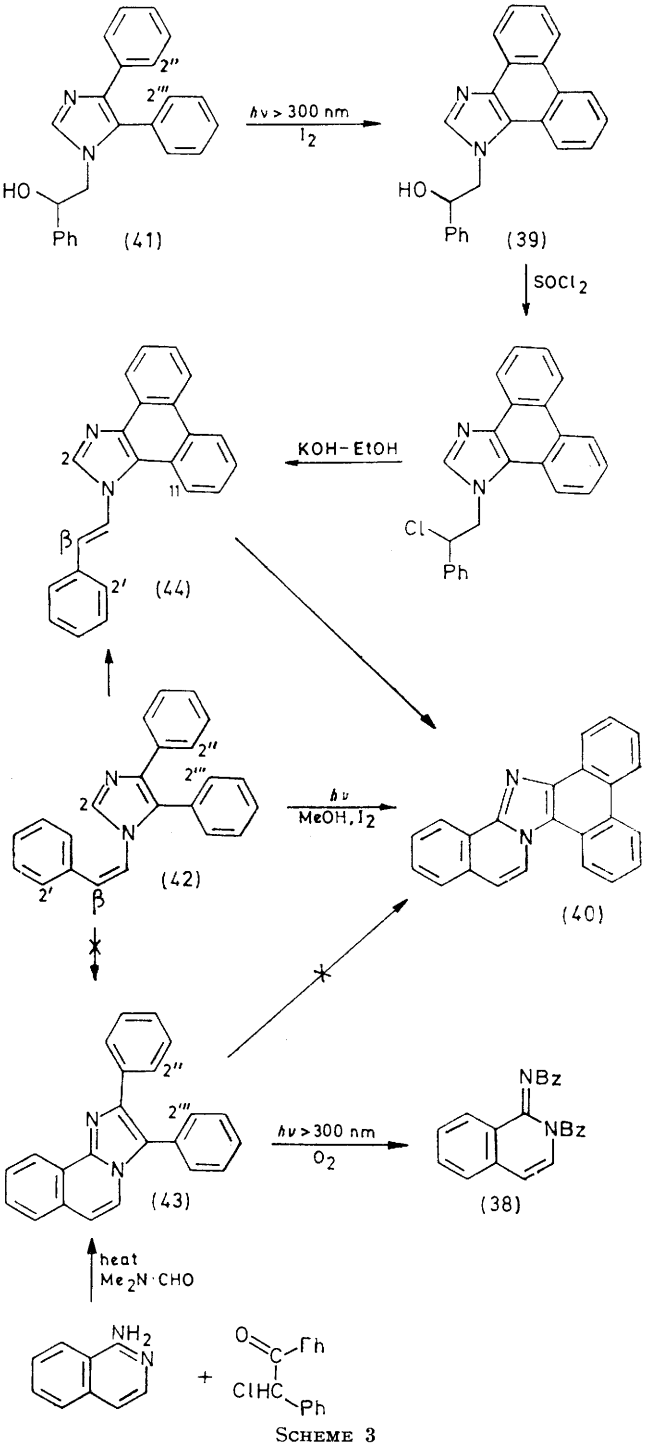
(36) (37)

been accomplished chemically by the action of lithium on 4,5-diphenylimidazole.[20] We considered that the photodehydrocyclisation of 4,5-diphenyl-1-styrylimidazole (42) might thus proceed in the imidazole mode to yield 2,3-diphenylimidazo[2,1-*a*]isoquinoline (43) or in the stilbene mode to give 1-styrylphenanthro[9,10-*d*]-imidazole (44), and that complete reaction should yield phenanthro[9',10':4,5]imidazo[2,1-*a*]isoquinoline (40), a hitherto unreported ring system. Initial photochemical experiments were conducted by irradiating the olefin (42) in a quartz cuvette and monitoring the resultant changes in u.v. absorption. On a preparative scale, a Pyrex-filtered source yielded a photostationary state after 15 h and a small yield (12%) of product ($\lambda_{max.}$ 280 nm) was isolated from a complex mixture. Use of unfiltered light gave the same compound (35%) and only small amounts of by-products were encountered. The increase in conjugation in comparison with the olefin (42) was shown by the presence of long-wave u.v. absorptions (at 362, 344.5, and 318 nm) and the intensity of the shorter-wave absorptions [$\lambda_{max.}$ (ε 81 100) and 259 (ε 56 900)]. The disappearance of the ^{1}H n.m.r. absorptions characteristic of the olefinic =CH and the appearance of a low field multiplet (τ 1.0) also suggested that cyclisation had taken place in the desired sense. The mass spectrum confirmed the identity of the product (40) by indicating a molecular weight ($M^{+\cdot}$ 319) four mass units less than that of 4,5-diphenyl-1-styrylimidazole (323).

This product could result from one or both of two different intermediates, namely, the imidazoisoquinoline (43) and the phenanthroimidazole (44). However, it proved impossible to isolate either of these from the photolysis mixture. With a view to obtaining more information about the course of the reaction the synthesis of these intermediates was undertaken. The phenanthroimidazole (44) was obtained from 1-(2-hydroxy-2-phenylethyl)-4,5-diphenylimidazole (41) by the conversions shown in Scheme 3. The final photodehydrocyclisation stage is of the stilbene type and proceeded smoothly under Pyrex-filtered light (8 h).

[19] J. L. Cooper and H. H. Wasserman. *Chem. Comm.*, 1964, 200.
[20] K. Volkamer, H. Kiese, and H. Zimmerman, *Tetrahedron*, 1972, **28**, 5667.

Irradiation of the product (44) yielded the hexacyclic compound (40). 2,3-Diphenylimidazo[2,1-*a*]isoquinoline (43) was synthesised by the condensation of α-chlorobenzyl phenyl ketone with 1-aminoisoquinoline. Irradiation did not yield a solution with the expected absorption ($\lambda_{max.}$ 280 nm) but a photostationary state was achieved after 15 h. The product showed carbonyl absorptions (1 685 and 1 700 cm^{-1}), and the mass spectrum indicated a molecular weight of 352. The



SCHEME 3

base peak at *m/e* 105 ($C_6H_5CO^+$) suggested the presence of benzoyl groups, and it was concluded that this product was 2-benzoyl-1-benzoylimino-1,2-dihydroisoquinoline (38), produced by photo-oxidation of the imidazole grouping.[21-24]

The course of events leading to the phenanthroimidazoisoquinoline (40) from 4,5-diphenyl-1-styrylimidazole can thus be depicted as in Scheme 3. The major initial reaction is a cyclisation of the stilbene ⟶ phenanthrene type, (42) ⟶ (44), proceeding *via* the non-polarised type of excited state, which eventually leads to the hexacyclic nucleus, (44) ⟶ (40), *via* the polarised excited states of the imidazole-type reaction.

TABLE 1

Theoretical criteria for rationalization of photochemical reactivity

Compd.	Mode	Cyclisn.	ΣF *	ΣS *	L *	*hν*	Δ*E*
(6)	2, 2′	Yes	1.161 7	1.449 4	2.092	398.62	1.5025
	5, 2′	No	1.050 3	1.597 4	2.454 9		
(7)	5, 2′	No	1.085 5	1.602 2	2.366 4	393.37	1.4533
(8)	5, 2′	No	1.038 9	1.615 2	2.536 4	384.52	1.3161
	2″, β	No	1.094 1	1.305 8	10.510 3		
(9)	2, 2′	Yes	1.169 6	1.426 8	1.165 5	379.64	1.3287
(10)	3, 2′	Yes		1.378 8			
(11)	2, 2′	Yes	1.074 0	1.614 7	1.214 8	384.52	1.3027
	5, 2	No	1.143 0	1.520 8	2.317 4		
(12)	2, 2′	Yes	1.059 1	1.629 3	1.414 8	371.38	1.1450
(13)	5, 2′	No	1.143 0	1.520 8	2.689 4	380.85	1.3027
(14)	5, 2′		1.057 1	1.766 4	2.386 9		
	2″, β		1.103 5	1.290	10.376 2		
(15)	2, 1′		1.244 7	1.349 0	1.092 9		
	5, 1′		1.190 8	1.385 5	2.340 4		
	2, 3′		0.999 3	1.858 7	1.417 8		
	5, 3′		0.945 4	1.895 2	2.618 5		
(16)	2, 2′		1.098 2	1.510 1	1.306 2		
	5, 2′		1.048 6	1.546 3	2.568 5		

hν is calculated for the longest wavelength u.v. absorption. Δ*E* is the MO difference for the third π ⟶ π * transition. *hν* = 75.08; Δ*E* + 284.4 kJ mol^{-1} (r = 0.97).

No evidence was found for the participation of the alternative pathway (42) ⟶ (43) to any major degree; in any case this cannot yield the observed final product (43) ⟶ (40) under these experimental conditions.

MO Calculations.—In all calculations it was found that in the HOMO of the first excited state, *i.e.* the orbital controlling cyclisation, the wave coefficients of atoms capable of undergoing cyclisation (*e.g.* 2,2′ and 5,2′) were of opposite sign. This is represented for 1-styrylimidazole in the Figure. This picture is consistent with the results of mechanistic studies concerning the geometry of dihydro-intermediates.[25-28] The three criteria, ΣF*, ΣS*, and L*, which may be of use in rationalising the photochemical reactivity are shown in Table 1 for 1-styrylimidazole (6). The free valence index sum, which may be expected to be a guide to cyclisation if the transition state for the reaction is essentially like the ground state, is larger for the cyclisation mode involving the 2-position of the imidazole ring than it is for the 5-position. The sum of the superdelocalisabilities in the excited state also suggests that cyclisation at the 2-position is preferred to cyclisation at the 4-position of the imidazole ring. (In the case of radical attack, ready reaction is suggested by a low superdelocalisability sum.) The final criterion, that of localisation energy, is also favourable and predicts the observed cyclisation at the 2-position. The localisation energy is the difference between the π-electron energy in the first excited state of the styrylimidazole and that of the ground state of the related dihydro-compound. It may be expected that L*, therefore, is related to the cyclisation process if the transition state resembles the dihydro-intermediate.

Thus, in the case of 1-styrylimidazole, all three criteria correctly predict the cyclisation mode, as is the case with simpler systems. However, the values determined by Laarhoven [7] (*i.e.* ΣF* >1, ΣS* <1.44, L* <3.48) are not absolute, for in our calculations both 2- and 5-positions are on the same side of the suggested barrier. A less satisfactory picture is apparent, however, when complex substituents are present. The criteria for methyl 1-styrylimidazole-4-carboxylate (11) in Table 1 have been calculated by using the coulomb and resonance integrals developed by Goodwin [29] for benzoic acid. In this case neither the sum of the free valence indices, nor the sum of superdelocalisabilities for radical attack in the first excited state shows a preference for cyclisation at the 2-position—the observed reaction pathway. However, it seems unlikely that the photocyclic transition state is comparable to the ground state olefin, particularly as excitation must involve charge localisation, and thus criteria for cyclisation based upon the

[21] E. H. White and M. J. C. Harding, *J. Amer. Chem. Soc.*, 1964, **86**, 5686.
[22] F. McCapra, *Quart. Rev.*, 1966, **20**, 485.
[23] H. H. Wasserman, K. Stiller, and M. B. Floyd, *Tetrahedron Letters*, 1968, 3277.
[24] T. Matsuura and I. Saito, *Tetrahedron Letters*, 1968, 3273; 1969, **25**, 549; *Tetrahedron*, 1969, **25**, 541; Y. Le-Roux, C. Nofre, and G. Peres, *Compt. rend.*, 1968, **266**, 1323.
[25] Th. J. H. M. Cuppen and W. H. Laarhoven, *J. Amer. Chem. Soc.*, 1972, **94**, 5914.
[26] F. B. Mallory and C. W. Mallory, *J. Amer. Chem. Soc.*, 1972, **94**, 6041.
[27] F. R. Stermitz, *Org. Photochem.*, 1967, **1**, 247.
[28] R. B. Woodward and R. Hoffman, *Angew. Chem. Internat. Edn.*, 1969, **8**, 781.
[29] T. H. Goodwin, *J. Chem. Soc.*, 1955, 4451.

ground state only must be open to question. The localisation energy, however, predicts the correct mode of cyclisation for methyl 1-styrylimidazole-4-carboxylate.

Table 1 records the calculated HMO properties for photocyclisation reactions of 1-styryl- (6), 2-methyl-1-styryl- (7), and 2-phenyl-1-styryl-imidazole (8) and the corresponding 4-methoxycarbonyl derivatives (11), (13), and (14), dimethyl 1-styrylimidazole-4,5-dicarboxylate (12), 1-styrylbenzimidazole (9), and 1-[2-(1- and 2-naphthyl)vinyl]imidazole, (16) and (15). It is apparent that no information regarding the possibility of photodehydrocyclisation resides in either free valence or superdelocalisability indices in this series [*cf.* (12) and (13)]; however the localisation energy is again useful. This criterion covers the range 1.166—2.092β for reactions which have been observed to proceed (2-cyclisation); values of 2.317—2.536β are obtained for cyclisation at the 5-position. It thus appears that a clear distinction in the magnitudes of L* is observable, and this may have predictive value. However, these values are substantially smaller than observed for stilbene ⟶ phenanthrene cyclisation.[4] The relative magnitudes of the localisation energies for both modes of cyclisation may be studied together in the various cyclisations depicted in Scheme 3.

The HMO parameters are summarised in Table 2 for

TABLE 2

HMO Parameters for compounds (41)—(44)

Compd.	Mode	Cyclisn.	ΣF *	ΣS *	L *
(42)	2, 2′	No	1.106 9	1.512 4	1.313 9
	2″, 2‴	Yes	0.970 7	1.538 7	3.434 3
	2‴, β	No	1.027 2	1.604 1	10.636 6
(44)	2, 2′	Yes	1.128 3	1.491 3	1.213 4
	11, β	No	1.093 9	1.379 9	11.975 7
(43)	2″, 2‴	No	0.990 9	1.495 9	3.416 3
(41)	2″, 2‴	Yes	1.019 3	1.430 6	3.545 8

each of the cyclisation modes. The localisation energies for the imidazole-type reactions [(42) 2,2′ and (44) 2,2′] are within the range of values which suggest cyclisation. This is also true for the stilbene-type pathways [(42) 2″,2‴ and (43) 2″,2‴] and although the last value is rather high, ΣF* and ΣS* are in accord with cyclisation criteria.[7]

However, the magnitudes of L* for the two modes of cyclisation are so different that no conclusions may be reached concerning the relative reactivities involved. There seems little doubt that this is a direct result of failure to achieve comparability between the transition states involved and suggests that some reappraisal of relative magnitudes of the parameters used in these calculations is necessary.

EXPERIMENTAL

I.r. spectra were determined for Nujol mulls, unless otherwise stated, with a Unicam SP 200 spectrophotometer. N.m.r. spectra were determined for solutions in deuteriochloroform, unless otherwise stated, with tetramethylsilane as internal standard, with a Varian A60-A spectrometer (or, if indicated, with a Varian HR220 spectrometer by the Physico-chemical Measurements Unit, Harwell). Mass spectra were determined with an A.E.I. MS9 spectrometer, operating at 100 μA and 70 eV. U.v. spectra were determined for solutions in methanol solution with a Beckmann Acta V spectrophotometer. Photochemical reactions were performed with a Hanovia 1 l photochemical reactor and a 100 Watt medium-pressure mercury arc. Preliminary experiments were conducted by monitoring changes in u.v. absorption during irradiation in a quartz cuvette. Reaction temperatures are those of an external oil-bath. Light petroleum refers to the fraction of boiling range 60—80 °C.

The HMO calculations were performed with an ICL 1905E computer by using a published program [30] as a basis to which have been added routines for the calculation of free valence and superdelocalisabilities.[31] The parameters used in these calculations [6,16,32,33] are recorded in Table 3.

TABLE 3

HMO Parameters

Atom	Coulomb integral	Resonance integral
=N–	0.5 (1.0)	0.8
$=\overset{+}{N}<$	2.0	1.0
$-\ddot{N}<$	1.5	1.0
Me–C=	−0.5	1.0
O ‖	1.25	1.414
–C	0.6	1.0
O	2.0	1.414

Dimethyl 2-Methylimidazole-4,5-dicarboxylate.—2-Methylimidazole-4,5-dicarboxylic acid (5.0 g) was added to methanol (100 cm³) previously saturated with hydrogen chloride gas. The mixture was heated under reflux until the acid had dissolved (1 h) and then adjusted to pH 4—5 with sodium hydroxide (20%). The resulting solution was evaporated to dryness and the residue was extracted with chloroform. The extract was filtered from sodium chloride and the filtrate was evaporated to yield the *diester* (4.5 g, 85%), m.p. 128—129°, as prisms (from benzene) (Found: C, 48.25; H, 5.3; N, 13.95. $C_8H_{10}N_2O_4$ requires C, 48.5; H, 5.05; N, 14.15%); $\nu_{max.}$ 1 710 (C=O), 1 730 (C=O), and 2 800 (N–H) cm⁻¹; τ ($CDCl_3$) 6.17 (6 H, s, 4- and 5-CO_2Me) and 7.5 (3 H, s, 2-Me); *m/e* 198 (40%), 184 (5), 168 (9), 167 (100), 153 (8), 140 (8), 139 (8), 136 (6), 135 (53), 110 (19), 109 (9), 108 (17), 107 (6), 94 (13), 84 (8), 82 (28), 81 (6), 79 (11), 78 (77), 77 (10), 67 (11), 59 (6), 54 (6), 53 (8), 52 (17), 51 (9), 50 (6), 43 (13), 42 (53), 41 (8), 40 (6), and 39 (8); *m** 109.13 (167 ⟶ 135) and 99.05 (184 ⟶ 135).

Methyl 1,6-Dihydro-5-hydroxy-6-oxo-2-phenylpyrimidine-4-carboxylate (25).—A mixture of benzamide oxime (1.36 g, 0.01 mol) and dimethyl but-2-ynedioate (1.42 g, 0.01 mol) in methanol (20 cm³) was heated under reflux for 1 h. The solution was evaporated and the residue was dissolved in chloroform. This solution was washed with water and dried ($MgSO_4$). Evaporation gave a mixture of *cis*- and *trans*-adducts as an oil, $\nu_{max.}$ 1 710 (C=O) and 3 350 cm⁻¹ (N–H); τ ($CDCl_3$) 4.04 (s, =C*H*-*trans*) and 4.19 (s, =C*H*-*cis*) (*cis* : *trans* 6.1 : 1). The adduct was heated under reflux in diethylene glycol dimethyl ether for 15 min. The solvent

[30] K. B. Wiberg, 'Computer Programming for Chemists,' Benjamin, New York, 1965.
[31] C. H. Schwalbe, University of Aston, unpublished work.
[32] W. P. Purcell and J. A. Singer, *J. Chem. and Eng. Data*, 1967, **12**, 235.
[33] A. Pullman and B. Pullman, *Rev. Mod. Phys.*, 1960, **32**, 428.

was evaporated off to leave a gummy residue which on trituration with ether gave the *pyrimidine* (0.8 g, 34%), m.p. 236—237°, as needles (from methanol) (Found: C, 58.6; H, 4.05; N, 11.35. $C_{12}H_{10}N_2O_4$ requires C, 58.55; H, 4.05; N, 11.4%); $\nu_{max.}$ 1 670 (C=O), 1 700 (C=O), and 3 150 cm^{-1} (O–H, N–H); τ [$(CD_3)_2SO$] 1.9 (2 H, m, 2′- and 6′-H), 2.45 (3 H, m, 3′-, 4′-, and 5′-H), and 6.1 (3 H, s, Me). The mother liquors, when evaporated, gave a solid (0.15 g) which proved to be a mixture of the pyrimidine ($M^{+\cdot}$ 246), *m/e* 247 (5%), 246 (37), 215 (5), 214 (24), 186 (8), 158 (9), 130 (7), 105 (6), 104 (100), 103 (11), 77 (19), and 51 (8%); *m** 186.2 (246 ⟶ 214), 161.6 (214 ⟶ 186), and 134.3 (186 ⟶ 158), and dimethyl imidazole-4,5-dicarboxylate ($M^{+\cdot}$ 260).

5-*Hydroxy*-2-*phenylpyrimidin*-4(3H)-*one* (28).—A solution of the foregoing ester (0.5 g) in concentrated hydrochloric acid (20 cm^3) was heated under reflux for 2 h and allowed to cool to yield the acid (26) (0.4 g, 85%), m.p. 221—222°, $\nu_{max.}$ 1 670 (C=O) and 3 250 (O–H) cm^{-1}; *m/e* 189 (12%), 188 (100), 144 (8), 142 (6), 117 (8), 116 (52), 115 (12), 105 (10), 104 (10), 103 (12), 89 (16), 77 (34), 76 (12), 63 (6), 57 (32), 51 (14), and 50 (8). A solution of the acid (0.4 g) in acetic anhydride (3 cm^3) was heated under reflux for 2 h and allowed to cool to yield 5-*acetoxy*-2-*phenylpyrimidin*-4(3H)-*one* (0.375 g, 94%) as white microneedles, m.p. 244—245° (from water) (Found: C, 62.1; H, 4.4; N, 12.3. $C_{12}H_{10}N_2O_3$ requires C, 62.6; H, 4.35; N, 12.15%); $\nu_{max.}$ 1 670 (C=O), 1 750 (C=O), and 3 100 cm^{-1} (N–H); τ [$(CD_3)_2SO$] 1.95 (1 H, s, 6-H), 1.95 (2 H, m, 2′- and 6′-H), 2.5 (3 H, m, 3′-, 4′-, and 5′-H), and 7.72 (3 H, s, Me), *m/e* 230 (3%), 189 (13), 188 (100), 187 (5), 144 (8), 116 (15), 115 (5), 104 (33), 103 (9), 89 (7), 78 (15), 77 (18), 76 (6), 57 (22), 51 (10), 50 (5), 43 (34), and 42 (6). A solution of the acetate (0.3 g) in concentrated hydrochloric acid (20 cm^3) was heated under reflux for 2 h, cooled, and evaporated. The residue was dissolved in the minimum volume of water and basified (20% NaOH) to pH 5—6 to precipitate the pyrimidine (28) (0.18 g, 73%), m.p. 221—222° (lit.,[15] 212—215°) as needles (from water) (Found: $M^{+\cdot}$, 188.058 605. Calc. for $C_{10}H_8N_2O_2$: *M*, 188.058 573); $\nu_{max.}$ 1 660 (C=O), 3 100 (N–H), and 3 450 cm^{-1} (O–H); τ [$(CD_3)_2SO$] 2.0 (2 H, m, 2′- and 6′-H), 2.39 (1 H, s, 6-H), and 2.50 (3 H, m, 3′-, 4′-, and 5′-*H*); $\lambda_{max.}$ (pH 1) 288 (ε 11 780) and 240 nm (11 200), (pH 11) 310 (12 700) and 227 nm (11 450) [lit.,[15] (pH 1) 287 (11 900) and 243 nm (10 000), (pH 11) 315 (13 700) and 230 nm (9 800)]; *m/e* 189 (12%) 188 (100), 144 (9), 142 (6), 117 (8), 116 (45), 115 (11), 105 (9), 104 (63), 103 (12), 89 (18), 77 (57), 70 (15), 75 (6), 63 (9), 57 (48), 52 (8), 51 (27), 50 (15), and 39 (9).

2-(1-*Naphthyl*)*oxiran* (33).—*N*-Bromosuccinimide (recrystallised from water; 27 g, 1.5 mol. equiv.), distilled water (40 cm^3), and 1-vinylnaphthalene (15.4 g, 1 mol. equiv.) were mixed, and acetone was added until one phase was achieved. After stirring for 16 h the solvents were removed under reduced pressure and an ethereal extract of the residue was washed with water, dried, and evaporated to yield the bromohydrin as a crude yellow oil, τ ($CDCl_3$) 1.9—2.6 (7 H, m, aromatic), 4.3 (1 H, q, C*H*·CH_2), and 6.3 (2 H, m, CH·C*H*$_2$). The bromohydrin in ether was stirred while sodium hydroxide solution (6.0 g in 150 cm^3) was added dropwise over 2 h. The ether layer was separated, washed with water, dried, and distilled *in vacuo* to give the epoxide (4.6 g, 61%) as a pale yellow oil, b.p. 110—120° at 1 mmHg, τ ($CDCl_3$) 1.9—2.9 (7 H, m, aromatic), 5.68 (1 H, q, C*H*·CH_2), and 6.88 (1 H, q, CH·C*H*H).

Reaction of 2-*Naphthyloxiran with Imidazole*.—The epoxide (1.87 g, 0.011 mol), imidazole (0.68 g, 0.01 mol), and potassium (0.04 g, 0.001 mol) were stirred in dimethylformamide for 16 h at room temperature. Water was added and the mixture extracted with chloroform. No products were isolated on basification of an acidic extract of this solution. However the original chloroform extract, after washing, drying, and evaporation, gave an oil, the chlorohydrin, b.p. 140—160° at 1 mmHg (0.75 g, 27%), τ ($CDCl_3$) 1.9—3.0 (7 H, m, aromatic), 4.30 (1 H, t, *J* 6 Hz, C*H*·CH_2), 6.02 (2 H, d, *J* 6 Hz, CH·C*H*$_2$), and 6.70 (1 H, removed on deuteriation, OH), $M^{+\cdot}$ 260.

Attempted Synthesis of 2-(2-*Naphthyl*)*oxiran*.—*N*-Bromosuccinimide (13.5 g, 1.5 mol. equiv.), water (20 cm^3), and 2-vinylnaphthalene (7.7 g) were mixed with acetone until one phase was achieved and then stirred for 16 h. The solvent was then evaporated off under reduced pressure and an ethereal extract of the residue was washed with water. This solution, containing the bromohydrin, was not purified further, but N-sodium hydroxide solution (74 cm^3) was added dropwise with rapid stirring over 2 h. The resulting ethereal solution was separated, washed with water, dried, and distilled to yield an oil (2.3 g, 28%), b.p. 160—165° at 1 mmHg. This proved to be a mixture of 2-acetylnaphthalene and 2-naphthylacetaldehyde (ratio 1 : 3), τ ($CDCl_3$) 0.43 (t, *J* 2.2 Hz, CH_2·C*H*O), 1.8—3.0 (aromatic), 6.45 (d, *J* 2.2 Hz, C*H*$_2$·CHO), and 7.52 (s, CH_3); $\nu_{max.}$ 2 830, 2 730 (aldehydic C–H), 1 720 (aldehydic C=O), and 1 680 cm^{-1} (ketonic C=O).

trans-1-*Styrylphenanthro*[9,10-d]*imidazole* (44).—1-(2-Hydroxy-2-phenylethyl)phenanthro[9,10-*d*]imidazole on treatment with thionyl chloride and subsequent treatment of the chlorosulphite with base gave, on addition of water, a precipitate of the *olefin* (0.6 g, 63%), m.p. 234—235°, as needles (from ethyl acetate) (Found: C, 86.05; H, 4.9; N, 8.5. $C_{23}H_{16}N_2$ requires C, 86.25; H, 5.0; N, 8.75%); $\nu_{max.}$ 1 655 cm^{-1} (C=C), τ [$(CD_3)_2SO$; 220 MHz] 1.01 (1 H, d, *J* 8 Hz, 7- or 8-H), 1.1 (1 H, d, *J* 8 Hz, 7- or 8-H), 1.4 (1 H, d, *J* 8 Hz, 4- or 11-H), 1.55 (1 H, d, *J* 8 Hz, 4- or 11-H), 1.45 (1 H, s, 2-H), 1.60 (1 H, d, *J* 14 Hz, N·CH=), 2.25—2.5 (9 H, m, 5-, 6-, 9-, and 10-H and Ph), and 2.71 (1 H, d, *J* 14 Hz, PhC*H*:); $\lambda_{max.}$ 349.5 (1 700) and 254 nm (76 700), *m/e* 321 (25%), 320 (100), 319 (45), 318 (11), 218 (6), 210 (6), 190 (10), 160 (16), 159 (8), 140 (6), 116 (5), 115 (12), 77 (12), 51 (6), 45 (5), 44 (10), and 43 (7).

Phenanthro[9′,10′:4,5]*imidazo*[2,1-a]*isoquinoline* (40).—A stirred solution of *trans*-1-styrylphenanthro[9,10-*d*]imidazole (0.6 g) and iodine (0.05 g) in methanol (1 l) was irradiated through a Pyrex filter. When u.v. spectroscopy indicated complete reaction (5.5 h), any free iodine was neutralised with sodium thiosulphate solution and the solution was evaporated to low bulk to precipitate the *product* (0.45 g, 75%), m.p. 253—254°, as pale yellow prisms (from ethyl acetate) (Found: C, 86.5; H, 4.5; N, 8.6. $C_{23}H_{14}N_2$ requires C, 86.8; H, 4.4; N, 8.8%); $\lambda_{max.}$ 362 (6 500), 344.5 (13 400), 318 (14 100), 280.5 (81 100), 259.5 (56 900), and 252sh nm (36 400), τ ($CDCl_3$; 220 MHz) 1.0 (2 H, m, 15-H and one of 4-, 5-, and 8-H), 1.18 (2 H, d, *J* 7.5 Hz, two of 4-, 5-, and 8-H), 1.3 (1 H, d, *J* 8 Hz, 1-H), 1.52 (1 H, d, *J* 8 Hz, 10-H), 2.3 (7 H, m, 2-, 3-, 6-, 7-, 12-, 13-, and 14-H), and 2.83 (1 H, d, *J* 8 Hz, 11-H), *m/e* 319 (28%), 318 (100), 317 (10), 316 (12), 210 (17), 190 (5), 168 (12), 159 (34), 158 (15), 140 (16), 139 (5), 80 (5), 64 (64), 58 (6), 55 (5), 48 (30), 45 (29), 44 (47), 43 (39), 42 (9), 41 (9), 40 (16), 39 (8), and 36 (23).

1-(2-*Hydroxy*-2-*phenylethyl*)*phenanthro*[9,10-d]*imidazole* (39).—A stirred solution of 1-(2-hydroxy-2-phenylethyl)-4,5-diphenylimidazole (1.0 g) and iodine (0.11 g) in methanol (1 l) was irradiated through Pyrex. When reaction was complete (8 h) any free iodine was neutralised with sodium thiosulphate solution and the solution was evaporated to low bulk to precipitate the *phenanthrene* (0.7 g, 70%), m.p. 264—265°, as needles (from methanol) (Found: C, 81.4; H, 5.3; N, 8.15. $C_{23}H_{18}N_2O$ requires C, 81.65; H, 5.35; N, 8.3%), $\nu_{max.}$ 3 200 cm^{-1} (OH), τ [$(CD_3)_2SO$; 220 MHz] 1.03 (1 H, d, *J* 8 Hz, 7- or 8-H), 2.00 (1 H, s, 2-H), 2.3 (4 H, m, 5-, 6-, 9-, and 10-H), 2.26 (5 H, m, Ph), 4.1 (1 H, d, *J* 5 Hz, OH), 4.95 (1 H, m, C*H*·CH_2), and 5.18 (2 H, m, CH·CH_2), $\lambda_{max.}$ 350 (2 100), 333 (1 800), 299.5 (8 100), 280 (14 000), 254 (88 800), 246.5 (65 000), and 238sh nm (35 500).

Photocyclisation of 4,5-*Diphenyl*-trans-1-*styrylimidazole*.—(i) A stirred solution of 4,5-diphenyl-*trans*-1-styrylimidazole (0.5 g) and iodine (0.05 g) in methanol (1 l) was irradiated through quartz (5 h) to yield the phenanthroimidazoisoquinoline (40) (0.175 g, 35%), identical with that synthesized by photocyclisation of *trans*-1-styrylphenanthro-[9,10-*d*]imidazole.

(ii) 4,5-Diphenyl-*trans*-1-styrylimidazole (0.5 g) and iodine (0.05 g) were irradiated in methanol (1 l) with stirring through Pyrex (15 h). The residue from this reaction was extracted with boiling light petroleum; evaporation gave an oil which was dissolved in the minimum volume of methanol, and the solution was refrigerated to yield the same phenanthroimidazoisoquinoline (40).

Photo-oxidation of 2,3-*Diphenylimidazo*[2,1-a]*isoquinoline* (43).—A stirred solution of 2,3-diphenylimidazo[2,1-*a*]isoquinoline (0.5 g) and iodine (0.04 g) in methanol (1 l) was irradiated through Pyrex (15 h) to yield an oil, which on trituration with a little ether gave 2-*benzoyl*-1-*benzoylimino*-1,2-*dihydroisoquinoline* (38) (0.2 g, 37%), m.p. 227—228°, as microprisms (from benzene–ether) (Found: C, 78.45; H, 4.7; N, 7.7. $C_{23}H_{16}N_2O_2$ requires C, 78.4; H, 4.55; N, 7.95%), $\nu_{max.}$ 1 685 (C=O) and 1 700 cm^{-1} (C=O), τ ($CDCl_3$) 1.76 (1 H, d, *J* 6 Hz, 3-H) and 2.0—2.9 (15 H, m, 4-, 5-, 6-, 7-, and 8-H and 2 × Ph), *m/e* 352 (5%), 351 (6), 247 (16), 206 (8), 105 (100), 77 (55), and 51 (10), *m** 298.2 (352 ⟶ 324), 270.5 (324 ⟶ 296), 173.4 (352 ⟶ 247), 56.46 (105 ⟶ 77), and 33.78 (77 ⟶ 51).

2,3-*Diphenylimidazo*[2,1-a]*isoquinoline* (43).—A solution of α-chlorobenzyl phenyl ketone (desyl chloride) (6.3 g, 0.03 mol) and 1-aminoisoquinoline (recrystallized from light petroleum; 6.0 g, 0.04 mol) in dimethylformamide (100 cm^3) was heated under reflux for 3 h. The solvent was evaporated off, the residue dissolved in chloroform, and the solution washed with water, dried ($MgSO_4$), saturated with hydrogen chloride gas, and stirred overnight in a stoppered flask to precipitate the hydrochloride of the imidazoisoquinoline. This was collected and stirred vigorously with 20% sodium hydroxide (50 cm^3) for 1 h to yield the *imidazoisoquinoline* (3.1 g, 45%), m.p. 158—159°, as needles (from methanol) (Found: C, 86.0; H, 5.0; N, 8.65. $C_{23}H_{16}N_2$ requires C, 86.25; H, 5.0; N, 8.75%), τ ($CDCl_3$) 1.25 (1 H, m, 10-H), 2.4 (1 H, d, *J* 7.5 Hz, 5-H), 2.1—2.5 (5 H, m, 7-, 8-, and 9-H and Ph *ortho*-protons), 2.54 (5 H, s, Ph), 2.73 (3 H, m, Ph *m*- and *p*-protons), and 3.1 (1 H, d, *J* 7.5 Hz, 6-H); $\lambda_{max.}$ 310sh (13 200) and 266 nm (60 500); *m/e* 321 (24%), 320 (100), 319 (64), 318 (15), 317 (5), 178 (5), 165 (8), 160 (16), 159 (11), 158 (5), 128 (6), 101 (5), and 87 (5).

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