Photochemical substitution of halogenopyrrole derivatives
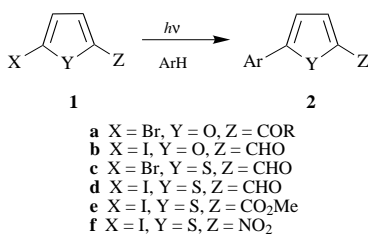
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The photochemical behaviour of some iodo substituted pyrroles when they are irradiated in the presence of an aromatic compound is reported. *N*-Methyl-3,4-diiodopyrrole-2-carbaldehyde and 5-iodopyrrole-2-carbaldehyde are unreactive when they are irradiated in benzene solution. In contrast, ethyl 3,4-dimethyl-5-iodopyrrole-2-carboxylate gives a 1:1 mixture of ethyl 3,4-dimethyl-5-phenylpyrrole-2-carboxylate and ethyl 3,4-dimethylpyrrole-2-carboxylate in quantitative yields. The same reaction when attempted with acetonitrile as solvent gives ethyl 3,4-dimethylpyrrole-2-carboxylate as the sole product in quantitative yield. Use of 4,5-diiodopyrrole-2-carbaldehyde as substrate and irradiation in benzene gives the corresponding 5-phenyl derivative. The same behaviour is observed with *m*-xylene, thiophene and 2-chlorothiophene as solvents. With acetonitrile as solvent, the reaction with benzene does not work. With 2-methylthiophene as solvent 2-(5-methyl-2-thienyl)-3-iodopyrrole is obtained as the sole product. The observed behaviour can be explained on the basis of the previously reported data on the mechanism of the photochemical arylation of halogenothiophene derivatives.

In recent years we have reported that halogenofuran and halogenothiophene derivatives **1** can be converted into the corresponding aryl derivatives **2** upon irradiation in the presence of aromatic or heteroaromatic compounds (Scheme 1).[1-9]

a X = Br, Y = O, Z = COR
b X = I, Y = O, Z = CHO
c X = Br, Y = S, Z = CHO
d X = I, Y = S, Z = CHO
e X = I, Y = S, Z = CO₂Me
f X = I, Y = S, Z = NO₂

Scheme 1

The mechanism of this reaction has been studied recently and shows some interesting features. Thus, although excitation of the substrate leads to a n,π* triplet state, the carbon–iodine bond in this excited state fails to cleave. This was demonstrated by the absence of coupling products when the n,π* triplet state was generated by sensitization with chrysene. Thus, probably the reaction occurs in a higher excited (π,σ*, n,σ*, or σ,σ*) triplet state mainly localized on the carbon–iodine bond. Furthermore, the interaction between this triplet state of the substrate and aromatic compounds leads to homolytic cleavage of the C–I bond and formation of both the radical **3** and a complex between the aromatic compound and the halogen atom. The formation of this complex was demonstrated by the presence of a short-lived transient with $\lambda_{max} = 510$ nm, showing second-order decay kinetics and a half-life of *ca.* 0.4 μs in laser flash photolysis. The thienyl radical thus formed reacts rapidly with the aromatic compound to form the corresponding arylation product (Scheme 2).[10]

There are no examples in the literature of the photochemical arylation of pyrrole derivatives. In conclusion, we have shown that there are a number of interesting reasons for studying the possible extension of the photochemical arylation of halogenoheterocyclic derivatives to pyrrole derivatives and here we report our results in this field.
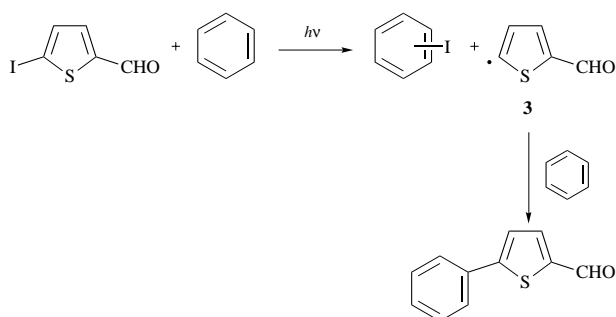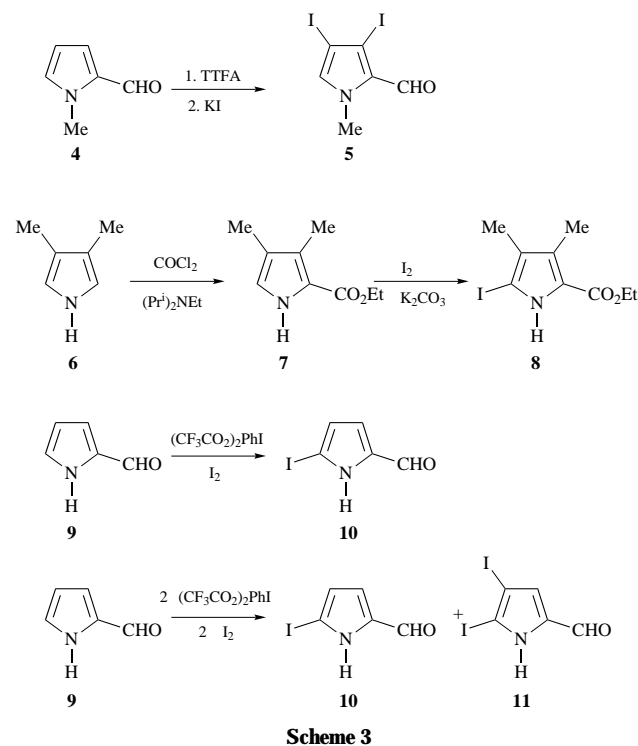

Scheme 2

Results and discussion

The first problem to be faced in work of the kind described here is the availability of iodo substituted pyrroles. It is known that pyrrole-2-carbaldehyde reacts with iodine in the presence of iodic acid to give an 85:15 mixture of 4-iodo- and 4,5-diiodopyrrole-2-carbaldehyde with an overall yield of 60%.[11] The first compound cannot be used in the photochemical reactions since it is necessary for the halogen-bearing carbons and the carbonyl group to be conjugated.[2] Reaction of the same substrate with iodine in the presence of HgO gave a mixture of 4-iodo-, 4,5-diiodo-, and 3,4-diiodo-pyrrole-2-carbaldehyde in a 82:14:4 ratio with an overall yield of 40%,[11] whereas the reaction of pyrrole-2-carbaldehyde with iodine and potassium iodide afforded a mixture of 5-iodo-, 4-iodo-, 4,5-diiodopyrrole-2-carbaldehyde in a 23:63:14 ratio with an overall yield of 35%.[11] Clearly, none of the preceding reactions can be used to obtain either 3- or 5-iodo-pyrrole derivatives in satisfactory yields.

A number of procedures were then tested in order to obtain selectively iodopyrroles suitable for our photochemical experiments. *N*-Methylpyrrole-2-carbaldehyde **4** was treated with thallium tris(trifluoroacetate) (TTFA)[12] and then with potassium iodide to give *N*-methyl-3,4-diodopyrrole-2-carbaldehyde **5** (Scheme 3);[13] also, we used ethyl 3,4-dimethyl-5-iodopyrrole-2-carboxylate **8** as substrate. This compound can be obtained from the reaction of 3,4-dimethylpyrrole **6**[14] with phosgene in the presence of *N*-ethyldiisopropylamine followed

Table 1 Photochemical arylation of halogenopyrrole derivatives

	Substrate	Reagent	Solvent	Irradiation time (h)	Product	Yields (%) [a]
	5	Benzene	—	5	—	—
	8	Benzene	—	6	**12**	50
					7	50
	8	Benzene	MeCN	4	**7**	100
	8	*m*-Xylene	—	4	**7**	100
	10	Benzene	—	8	—	—
	11	Benzene	—	6	**13**	100
	11	Benzene	MeCN	6	—	—
	11	*m*-Xylene	—	23	**15**	57
	11	Thiophene	—	6	**17**	78
	11	2-Chlorothiophene	—	22	**19**	85
	11	2-Methylthiophene	—	24	**21**	40

[a] All the yields refer to isolated chromatographically pure compounds.

Scheme 3

Scheme 4

by solvolytic treatment with absolute ethanol to give ethyl 3,4-dimethylpyrrole-2-carboxylate **7**;[15] the reaction of this with iodine in the presence of potassium carbonate (Scheme 3) then gives **8**.
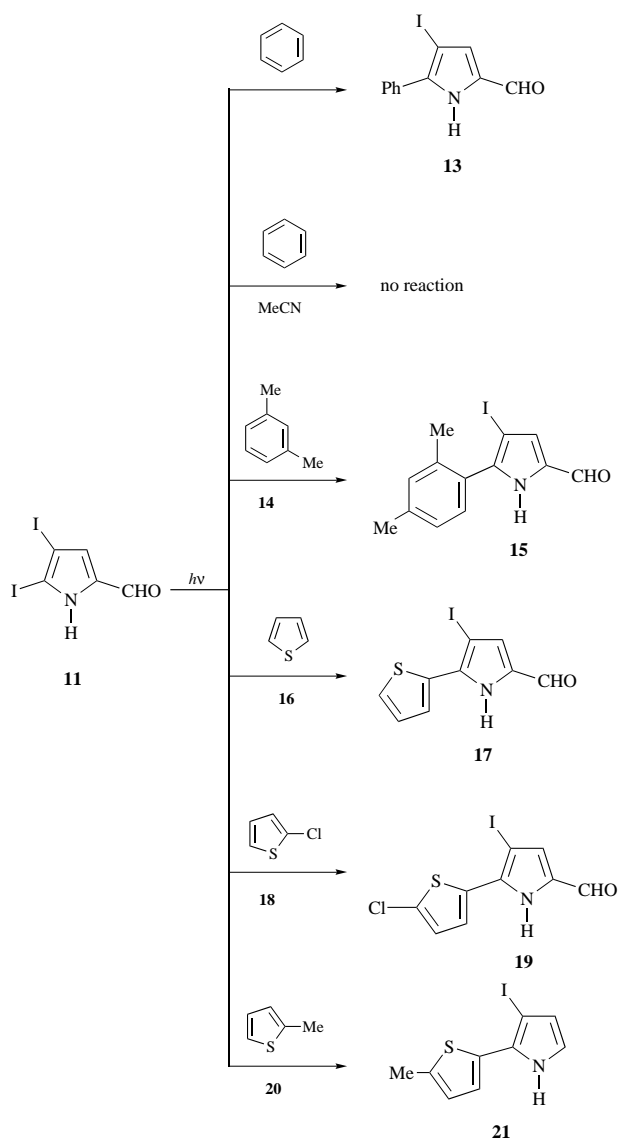
Further substrates used were 5-iodo and 4,5-diiodo-pyrrole-2-carbaldehyde. Recently we showed that bis(trifluoroacetoxy)-iodobenzene in the presence of iodine[17] conveniently iodinates thiophene derivatives.[18] We tested this reagent with pyrrole-2-carbaldehyde **9** and found that it can be useful in the selective synthesis of 5-iodopyrrole-2-carbaldehyde **10** (Scheme 3); with an excess of the reagent the major product was 4,5-diiodo-pyrrole-2-carbaldehyde **11** (Scheme 3).

The irradiation of *N*-methyl-3,4-diiodopyrrole-2-carbalde-hyde **5** in benzene with a high-pressure mercury arc proved to be ineffective, only unchanged **5** being recovered from the reaction mixture after 24 h of irradiation (Scheme 4, Table 1). Although use of 5-iodopyrrole-2-carbaldehyde **10** with prolonged irradiation in benzene solution gave a similar result (Scheme 4, Table 1) the behaviour of ethyl 3,4-dimethyl-5-iodopyrrole-2-carboxylate **8** was different. In fact, irradiation of **8** in benzene gave a mixture of two products in a 1 : 1 ratio with an overall yield of 100% (Scheme 4, Table 1). The ^{1}H NMR spectra of the products clearly showed that they were the phenyl derivative **12** and the dehalogenated product **7**. Use of aceto-nitrile as a solvent, shown earlier to be the best in this type of reaction,[8] for the irradiation of compound **8** in the presence of
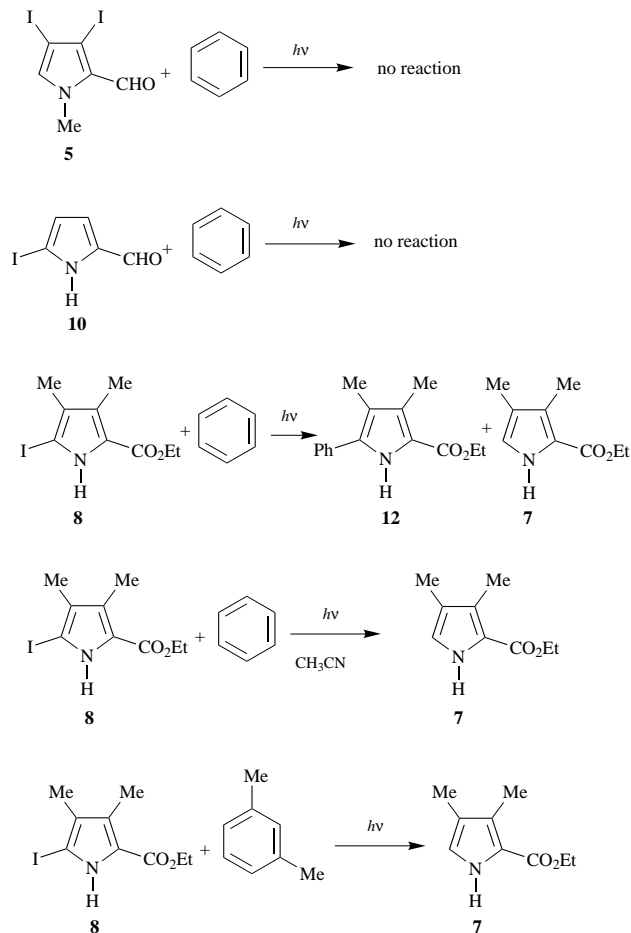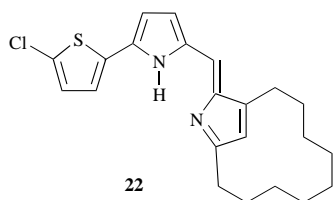
benzene gave nearly quantitative yields of the dehalogenated product **7** (Scheme 4, Table 1); a similar result was obtained for the reaction in *m*-xylene. Use of this compound as both reagent and solvent gave compound **7** as the sole product (Scheme 4, Table 1). Although in this case, there is photochemical aryl-ation, the occurrence of competitive dehalogenation makes this reaction useless for synthesis of the arylation product.

Use of 4,5-diiodopyrrole-2-carbaldehyde **11** [absorbs in the UV spectrum at λ 211 mm (log ε 3.54), 255 nm (log ε 3.68) and 299 nm (log ε 3.71)] as substrate gave a different pattern of behaviour. Thus, irradiation of **11** in benzene gave the corresponding phenyl derivative **13** in 100% yield (Scheme 5, Table 1), no dehalogenation product being formed. Although no reaction of **11** with benzene occurred upon irradiation in acetonitrile (Scheme 5, Table 1), in *m*-xylene we obtained solely the corresponding arylation product **15** (57%) (Scheme 5, Table 1). In this case, therefore, there is no competition between substitution and dehalogenation.

Scheme 5

Ph — CHO **13**

no reaction

MeCN

14 Me, Me → **15** (Me, Me, I, CHO)

11 (I, I, CHO, N–H) $h\nu$

16 (thiophene) → **17** (I, CHO)

18 (2-chlorothiophene, Cl) → **19** (Cl, I, CHO)

20 (2-methylthiophene, Me) → **21** (Me, I)

Scheme 6

23 (OMe, Br, naphthoquinone) $\xrightarrow[\text{benzene}]{h\nu}$ **24** (OMe, N–Me pyrrolyl)

23 N-Me pyrrole

Me–N, Me–N uracil, I $\xrightarrow[\text{Ph pyrrole}]{h\nu,\ \text{MeCN}}$ condensed product (Me, Me, N)
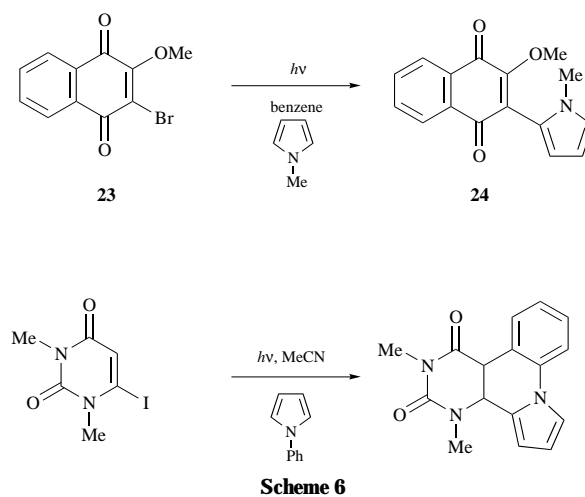
22 (Cl, thiophene, pyrrole, N–H, macrocycle)

Irradiation of compound **11** with thiophene **16** gave the corresponding 4-iodo-5-(2-thienyl)pyrrole-2-carbaldehyde **17** (78%) (Scheme 5, Table 1).

A similar result was obtained when 2-chlorothiophene was used as both reagent and solvent giving the corresponding 5-(5-chloro-2-thienyl) derivative **19** (85%) (Scheme 5, Table 1).

5-Arylpyrrole derivatives can be used in the synthesis of biologically active compounds such as **22**, related to metacycloprodigiosin:[19,20] indeed, the product thus obtained is very similar (the only difference is the presence of an iodine substituent on the pyrrole ring) to a key intermediate in the synthesis of **22**.

Finally, we used as solvent 2-methylthiophene. The irradiation of compound **11** in 2-methylthiophene gave mainly the decarbonylated arylation product **21** (as shown by mass spectrometry) (Scheme 5, Table 1), a compound never observed before.

Pyrrole derivatives were also used as aromatic partners in arylation reactions with a number of halogeno-containing compounds, *e.g.* the quinone **23** reacts with *N*-methylpyrrole to give the corresponding pyrrolyl derivative **24** (Scheme 6);[21] this reaction occurs *via* a charge transfer complex in the ground state. Several examples are known of the photochemical arylation on halogenoheterocyclic compounds.[22,23] Halogeno-pyridines were arylated when irradiated in the presence of pyrrolyl derivatives. Thus, 2-iodopyridine with *N*-methylpyrrole gave a low yield of the coupling product, while 3- and 4-iodopyridine gave very high yields of the corresponding coupling products;[24–26] similar results were obtained with quinoline derivatives.[27] Pyrimidine derivatives also gave coupling products; with these, chloro- and iodo-derivatives were used as substrates showing that usually the chlorine atom is not involved in the reaction.[28] The same behaviour was observed using halogeno-uracils or -purines as substrates.[29–31] With the former, use of *N*-phenylpyrrole as the reagent, gave a double arylation leading to condensed products (Scheme 6).

In all the above reported reactions pyrroles as substrates were allowed to react in the presence of halogenoaromatics; there are no reports in the literature of the arylation of halogeno-pyrroles. Furthermore, since hitherto aryl substituted pyrrole-2-carbaldehydes could only be synthesized by a Vilsmeier–Haack reaction or by reaction of the stannyl derivatives with halogeno substituted aryl compounds in the presence of a Pd[II] catalyst,[32–34] the described photochemical method represents a new approach to their synthesis. Also it constitutes a new photochemical reaction where halogenopyrroles react to give, through their excited states, the corresponding arylation products.

Our results allow us to draw the following conclusions on the reactivity of halogenopyrroles. First, although some pyrrole derivatives are unreactive, this was not observed with furan or thiophene derivatives.[2,3] In such cases the only unreactive species had a 4-halogeno substituent on the heterocyclic ring. Furthermore, although substrates having a 3-halogeno substituent on the heterocyclic ring gave only low yields of the corresponding arylation products, they were reactive. In contrast, substrates having a 3- or a 5-halogeno substituent, *e.g.* **5** and **10**, are completely unreactive. Furthermore, in the case of the substrate **8**, the arylation product was formed only in the presence of a competitive dehalogenation, a reaction which predominated in most of the experiments reported. With furan and thiophene derivatives we observed dehalogenation only with 5-iodothiophene-2-carbonitrile and 5-chloro-2-acetyl-thiophene.[7,35]

The difference in the photochemical behaviour of compounds **5**, **10** and **11** may be explained as follows. In earlier work, we found that the described reaction probably occurs as a result of homolytic cleavage of the C–I bond in an excited triplet state showing π,σ^*, n,σ^* or σ,σ^* character.[10] Such is the difference in energy of each of these states that the observed

reactivities differ. Compounds **5** and **10** thus may be unable to populate the corresponding excited triplet states and, therefore, fail to react.

Although we cannot calculate the energy of these triplet states, we are able to calculate the energy of the lowest excited triplet state by using semiempirical methods (AM1). In this way, for compounds **5** and **10** the lowest triplet state was shown to have an energy of 62 and 63 kcal mol^{-1}, respectively. In contrast, for compound **11** the same triplet state had an energy of 54 kcal mol^{-1}. Obviously, this calculation is not strictly related to the energy of a higher triplet state. However, if the lowest triplet state of compound **11** has a lower energy than the energies of compound **5** and **10**, it is likely that the same trend will be reflected in the higher triplet states. In conclusion, the reactive triplet state of compound **11** may be at a lower energy than those of compounds **5** and **10**, and, therefore is capable of being populated more easily.

Experimental

Mass spectra were obtained with a Hewlett-Packard 5971 mass selective detector on a Hewlett-Packard 5890 gas chromatograph. Gas chromatographic analyses were obtained by using an OV-1 capillary column in the range 70–250 °C (20 °C min^{-1}). Alternatively, mass spectra were obtained at 70 eV with a Kratos MS-80 instrument by direct insertion at a source temperature of 150 °C. A Cary 2300 spectrophotometer was used for the UV spectra. ^{1}H and ^{13}C NMR spectra were recorded with Varian EM-360, Varian Gemini 200 MHz, and Bruker 300 AM instruments. IR spectra were obtained on a Perkin–Elmer 457 spectrophotometer whilst elemental analyses were obtained with a Carlo Erba Elemental Analyzer 1106.

3,4-Dimethylpyrrole 6
To a solution of ethyl carbamate (27.1 g) in anhydrous benzene (150 cm^3) were added dropwise, using two dropping funnels, pyridine (35 cm^3) and thionyl chloride (15 cm^3). The mixture was stirred at room temperature for 1 h after which 2,3-dimethylbutadiene (25 g) was added to it. The mixture was refluxed and then stirred overnight. Pyridine hydrochloride was filtered off and washed with benzene. The filtrate and washings were then evaporated under reduced pressure to give 2-ethoxy-carbonyl-3,6-dihydro-4,5-dimethyl-1,2-thiazine 1-oxide [ν_{max}-(film)/cm^{-1} 1725, 1317, 1250 and 1100]. A solution of KOH (135 g) in methanol (300 cm^3) was added to the residue and the mixture was refluxed for 2 h. The solvent was then removed by distillation at ambient pressure, after which the residue was steam distilled to give an oil which was extracted many times with ether. The combined extracts were dried (K$_2$CO$_3$) and evaporated and the residual oil then distilled *in vacuo* to give 3,4-dimethylpyrrole (17.7 g, 0.1 mol, 48%); bp 67–70 °C/25 mmHg.

Ethyl 3,4-dimethylpyrrole-2-carboxylate 7
To a well-stirred 0.5 M solution of *N*-ethyldiisopropylamine in anhydrous toluene a 0.5 M solution of 3,4-dimethylpyrrole in toluene and a 0.5 M solution of phosgene in toluene were added at 0 °C *via* two dropping funnels; the amine, pyrrole derivative and phosgene were in a 1:1:1 ratio. The mixture was maintained at 0 °C overnight after which it was filtered into absolute ethanol as soon as possible. The ethanolic solution was maintained at 0 °C for 1 h. The solvent was removed by evaporation and the residue was steam distilled; finally the residue was recrystallized from hexanes to give compound **7** (16.7 g, 0.1 mmol, 57%); mp 95 °C (lit.,[36] 95–96 °C); spectroscopic data given below.

Ethyl 3,4-dimethyl-5-iodopyrrole-2-carboxylate 8
To a solution of ethyl 3,4-dimethylpyrrole-2-carboxylate (0.5 g, 3 mmol) in 60% methanolic K$_2$CO$_3$ (10 cm^3) with vigorous stirring was added a solution of iodine (0.8 g) in methanol (25 cm^3); after 10 min a white precipitate appeared. The mixture

was stirred for 2 h at room temperature and then overnight at 0 °C. The resulting precipitate was filtered off and washed with cold water to give **8** (732 mg, 2.5 mmol, 85%) (Found: C, 36.8; H, 4.2; N, 4.9. Calc. for C$_9$H$_{12}$IO$_2$N: C, 36.88; H, 4.13; N, 4.78%); δ_H(200 MHz, CDCl$_3$) 8.75 (s, 1 H), 4.28 (q, 2 H, *J* 7), 2.27 (s, 3 H), 1.94 (s, 3 H) and 1.33 (t, 3 H, *J* 7); *m/z* 293 (M$^+$).

5-Iodopyrrole-2-carbaldehyde 10
A solution of pyrrole-2-carbaldehyde (180 mg) in CCl$_4$ (3 cm^3) was treated with iodine (250 mg) and bis(trifluoacetoxy)iodo-benzene (420 mg). The mixture was stirred for 24 h after which it was extracted with ether. The extract was washed with 0.1 M aqueous Na$_2$S$_2$O$_3$, dried (Na$_2$SO$_4$) and evaporated to yield a crude product that was chromatographed on silica gel. Elution with hexane–EtOAc (8:2) gave 5-iodopyrrole-2-carbaldehyde (125 mg, 30%); small amounts of 4,5-diiodopyrrole-2-carbaldehyde (3%) were also obtained; mp 93–94 °C (lit.,[11] 94 °C); δ_H(300 MHz, CDCl$_3$) 9.47 (s, 1 H), 7.19 (d, 1 H, *J* 3) and 7.08 (d, 1 H, *J* 3); *m/z* 221 (100%), 220 (28), 192 (24), 127 (27), 65 (18), 39 (15) and 38 (18).

4,5-Diiodopyrrole-2-carbaldehyde 11
A solution of pyrrole-2-carbaldehyde (176 mg) in CCl$_4$ (3 ml) was treated with iodine (495 mg) and bis(trifluoacetoxy)iodo-benzene (843 mg). The mixture was stirred for 24 h after which it was extracted with ether. The extract was washed with 0.1 M aqueous Na$_2$S$_2$O$_3$, dried (Na$_2$SO$_4$) and evaporated to yield a crude product that was chromatographed on silica gel. Elution with hexane–EtOAc (8:2) gave 5-iodopyrrole-2-carbaldehyde (43 mg, 10%) and 4,5-diiodopyrrole-2-carbaldehyde (200 mg, 31%); mp of the latter 175–176 °C (lit.,[11] 176 °C); δ_H(300 MHz, CDCl$_3$) 9.26 (s, 1 H) and 6.97 (s, 1 H); *m/z* 347 (100%), 346 (27), 254 (10), 191 (16), 165 (28), 164 (23), 127 (45), 65 (18), 64 (14), 38 (15) and 37 (13).

Irradiation of ethyl 3,4-dimethyl-5-iodopyrrole-2-carboxylate
A solution of ethyl 3,4-dimethyl-5-iodopyrrole-2-carboxylate (100 mg) in benzene (10 cm^3) was flushed with nitrogen for 1 h. The mixture was then irradiated with a 500-W high-pressure mercury arc (Helios-Italquartz) surrounded by a Pyrex water-jacket for 6 h. The mixture was then diluted with chloroform, washed with 0.1 M aqueous Na$_2$S$_2$O$_3$, dried (Na$_2$SO$_4$) and evaporated to yield a crude product which was chromatographed on silica gel. Elution with hexane–chloroform (2:3) gave ethyl 3,4-dimethyl-5-phenylpyrrole-2-carboxylate **12** (40 mg, 50%) and ethyl 3,4-dimethylpyrrole-2-carboxylate **7** (26 mg, 49%). Compound **12**: a very dense oil (Found: C, 74.2; H, 7.0; N, 5.9. Calc. for C$_{15}$H$_{17}$O$_2$N: C, 74.04; H, 7.05; N, 5.76%); δ_H(200 MHz, CDCl$_3$) 8.96 (s, 1 H), 7.43 (m, 5 H), 4.29 (q, 2 H, *J* 7), 2.32 (s, 3 H), 2.13 (s, 3 H) and 1.35 (t, 3 H, *J* 7); ν_{max}(CHCl$_3$)/cm^{-1} 3450, 1675, 1600, 1565, 1455, 1430, 1280, 1120, 1065 and 1005; *m/z* 243 (M$^+$). Compound **7**: δ_H(200 MHz, CDCl$_3$) 8.92 (s, 1 H), 6.64 (s, 1 H), 4.28 (q, 2 H, *J* 7), 2.25 (s, 3 H), 1.99 (s, 3 H) and 1.33 (t, 3 H, *J* 7); *m/z* 143.

Irradiation of ethyl 3,4-dimethyl-5-iodopyrrole-2-carboxylate in acetonitrile
A solution of ethyl 3,4-dimethyl-5-iodopyrrole-2-carboxylate (100 mg) in acetonitrile (8 cm^3) in the presence of benzene (2 cm^3) was flushed with nitrogen for 1 h. The mixture was then irradiated with a 500-W high-pressure mercury arc (Helios-Italquartz) surrounded by a Pyrex water-jacket for 6 h. The mixture was then diluted with chloroform, washed with 0.1 M aqueous Na$_2$S$_2$O$_3$, dried (Na$_2$SO$_4$) and evaporated to yield a crude product which was chromatographed on silica gel. Elution with hexane–chloroform (2:3) gave ethyl 3,4-dimethyl-pyrrole-2-carboxylate **7** (53 mg, 100%).

Irradiation of 4,5-diiodopyrrole-2-carbaldehyde in benzene
A solution of 4,5-diiodopyrrole-2-carbaldehyde (68 mg) in benzene (10 cm^3) was flushed with nitrogen for 1 h. The mixture

was then irradiated with a 125-W high-pressure mercury arc (Helios Italquartz) surrounded by a Pyrex water jacket. After 6 h, the mixture was diluted with ether, washed with 0.1 M aqueous $Na_2S_2O_3$, dried (Na_2SO_4) and evaporated to yield pure 4-iodo-5-phenylpyrrole-2-carbaldehyde **13** (59 mg, 100%) as a very dense oil (Found: C, 44.6; H, 2.7; N, 4.6. Calc. for $C_{11}H_8ION$: C, 44.45; H, 2.71; N, 4.72%); δ_H(300 MHz, $CDCl_3$) 9.50 (s, 1 H), 7.65 (m, 2 H), 7.40 (m, 3 H) and 7.20 (s, 1 H); *m/z* 298 (12%), 297 (100), 296 (35), 141 (23), 140 (13), 115 (44), 114 (33), 113 (16), 88 (11) and 63 (11).

Irradition of 4,5-diiodopyrrole-2-carbaldehyde in *m*-xylene

A solution of 4,5-diiodopyrrole-2-carbaldehyde (80 mg) in *m*-xylene (10 cm³) was flushed with nitrogen for 1 h. The mixture was then irradiated with a 125-W high-pressure mercury arc (Helios Italquartz) surrounded by a Pyrex water jacket. After 23 h, the mixture was diluted with ether, washed with 0.1 M aqueous $Na_2S_2O_3$, dried (Na_2SO_4) and evaporated to yield crude product which was chromatographed on silica gel. Elution with hexane–EtOAc (7:3) gave pure 4-iodo-5-(2,4-dimethylphenyl)pyrrole-2-carbaldehyde **15** (41 mg, 57%) as a very dense oil (Found: C, 47.9; H, 2.8; N, 4.4. Calc. for $C_{13}H_{12}ION$: C, 48.00; H, 2.71; N, 4.31%); δ_H(300 MHz, $CDCl_3$) 9.45 (s, 1 H), 7.3–7.0 (m, 4 H), 2.40 (s, 3 H) and 2.22 (s, 3 H); *m/z* 325 (100%), 198 (42), 170 (63), 169 (33), 168 (28), 167 (12), 155 (47), 154 (45), 153 (19), 143 (25), 142 (10), 141 (31), 139 (13), 129 (10), 128 (43), 127 (22), 115 (35), 77 (14), 63 (13), 51 (10) and 39 (13).

Irradiation of 4,5-diiodopyrrole-2-carbaldehyde in thiophene

A solution of 4,5-diiodopyrrole-2-carbaldehyde (54 mg) in thiophene (10 cm³) was flushed with nitrogen for 1 h. The mixture was then irradiated with a 125-W high-pressure mercury arc (Helios Italquartz) surrounded by a Pyrex water jacket. After 6 h, the mixture was diluted with ether, washed with 0.1 M aqueous $Na_2S_2O_3$, dried (Na_2SO_4) and evaporated to yield a crude product which was chromatographed on silica gel. Elution with hexane–Et$_2$O (1:1) gave pure 4-iodo-5-(2-thienyl)pyrrole-2-carbaldehyde **17** (37 mg, 78%) as a very dense oil (Found: C, 35.5; H, 2.2; N, 4.5. Calc. for C_9H_6IONS: C, 35.65; H, 2.00; N, 4.62%); δ_H(300 MHz, $CDCl_3$); 9.45 (s, 1 H), 7.61 (dd, 1 H, J_1 4, J_2 1), 7.44 (dd, 1 H, J_1 5, J_2 1), 7.16 (m, 1 H) and 7.07 (m, 1 H); *m/z* 304 (12%), 303 (100), 302 (20), 148 (11), 147 (11), 121 (19) and 120 (19).

Irradiation of 4,5-diiodopyrrole-2-carbaldehyde in 2-chlorothiophene

A solution of 4,5-diiodopyrrole-2-carbaldehyde (79 mg) in 2-chlorothiophene (10 cm³) was flushed with nitrogen for 1 h. The mixture was then irradiated with a 125-W high-pressure mercury arc (Helios Italquartz) surrounded by a Pyrex water jacket. After 22 h, the mixture was diluted with ether, washed with 0.1 M aqueous $Na_2S_2O_3$, dried (Na_2SO_4) and evaporated to yield crude product which was chromatographed on silica gel. Elution with hexane–EtOAc (7:3) gave pure 4-iodo-5-(5-chloro-2-thienyl)pyrrole-2-carbaldehyde **19** (65 mg, 85%) as a very dense oil (Found: C, 32.2; H, 1.4; N, 4.2. Calc. for C_9H_5ClIONS: C, 32.06; H, 1.50; N, 4.16%); δ_H(300 MHz, $CDCl_3$) 9.40 (s, 1 H), 7.44 (d, 1 H, *J* 6), 7.22 (d, 1 H, *J* 6) and 7.16 (m, 1 H); *m/z* 338 (37%), 336 (100), 335 (35), 181 (10), 155 (12), 154 (10), 119 (20) and 93 (14).

Irradiation of 4,5-diiodopyrrole-2-carbaldehyde in 2-methylthiophene

A solution of 4,5-diiodopyrrole-2-carbaldehyde (86 mg) in 2-methylthiophene (10 cm³) was flushed with nitrogen for 1 h. The mixture was then irradiated with a 125-W high-pressure mercury arc (Helios Italquartz) surrounded by a Pyrex water jacket. After 24 h, the mixture was diluted with ether, washed

with 0.1 M aqueous $Na_2S_2O_3$, dried (Na_2SO_4) and evaporated to yield a crude product which was chromatographed on silica gel. Elution with hexane–EtOAc (8:2) gave pure 3-iodo-2-(5-methyl-2-thienyl)pyrrole **21** (29 mg, 40) as a very dense oil (Found: C, 37.2; H, 2.6; N, 5.0. Calc. for C_9H_8INS: C, 37.38; H, 2.79; N, 4.85%); δ_H(300 MHz, $CDCl_3$) 7.20 (m, 1 H), 6.95 (m, 1 H), 6.70 (d, 1 H, *J* 3), 6.60 (d, 1 H, *J* 3) and 2.48 (s, 3 H); *m/z* 292 (2%), 291 (14), 290 (18) and 289 (90).

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