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Identification by NMR and MS of the By-products Formed During the Synthesis of the Red Vat Dye 1,1′-Diethyl-(3,3′-bianthra[1,9-*c*,*d*]pyrazole)-6,6′(1*H*,1′*H*)-dione

Libuše Havlíčková, Alois Koloničný, Antonín Lyčka,
Josef Jirman & Ivan Kolb

Research Institute of Organic Syntheses, 532 18 Pardubice-Rybitví, Czechoslovakia

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ABSTRACT

*The bis-ethylation of (3,3,′-bianthra[1,9-*c,d*]pyrazole)-6,6′-dione, i.e. bispyrazoloanthrone, gives the red vat dye 1,1′-diethyl-(3,3′-bianthra[1,9-*c,d*]pyrazole)-6,6′(1*H,1′*H*)-dione, together with an orange isomer with ethyl groups in the 1,2′-positions and a yellow isomer having ethyl groups in the 2,2′-positions. The structures of these products were determined by one- and two-dimensional NMR spectroscopy and by mass spectroscopy.*

1 INTRODUCTION

The tautomerism in anthra[1,9-*c*,*d*]pyrazol-6-one (**I**) is confirmed by existence of two positional isomers **II** and **III** after alkylation. In the case of the bis-alkylation of the dye intermediate bispyrazoloanthrone (**IV**), three alkylation products can be expected, viz. symmetrical 1,1′-dialkyl-(3,3′-bianthra[1,9-*c*,*d*]pyrazole)-6,6′(1*H*,1′*H*)-dione (**V**), the asymmetrical 1,2′-dialkyl isomer **VI** and the symmetrical 2,2′-dialkyl isomer **VII**.

Japanese authors[1,2] have attempted to explain the structure of Vat Red 13 (CI 70320)[3] and of by-products that arise during its preparation by bis-ethylation of (3,3′-bianthra[1,9-*c*,*d*]pyrazole)-6,6′-dione (**IV**). Structure **Vb** was assigned to the principal product, viz. Vat Red 13. The orange product, isolated from the filter liquor, was given the formula **VIIb**,[1,2] although no

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reference was made to the steric hindrance which might prevent the formation of compound **VIIb** by dimerisation of **IIb**. Whilst alkali fusion of isomer **IIIb** gives the expected dye **Vb** the account is a *circulus in demonstrando* since structure **IIb** was assigned to one of the isomeric ethyl-(anthra[1,9-*c*,*d*]pyrazol)-6-ones solely on the basis of its dimerisation to dye **Vb**. A more detailed study of the methyl derivatives of anthra-[1,9*c*,*d*]pyrazol-6-ones[4,5] supported *per analogiam* the conclusions[1,2] on the constitutions of compounds **IIb**, **IIIb** and **Vb**. The vat dye **Va** was obtained by dimerisation of **IIIa**. A very difficult dimerisation of **IIa** resulted in the formation of a soluble orange compound and the structures of **IIa** and **IIIa** were proved by preparation of authentic samples.

The object of this present work was to study the structures of the two *N*-ethyl derivatives of **I** described in the literature and to identify by means of one- and two-dimensional ^{1}H- and ^{13}C-NMR and mass spectra both the orange and the yellow by-products which appear during the preparation of Vat Red 13 (CI 70320) by ethylation of (3,3′-bianthra[1,9-*c*,*d*]pyrazole)-6,6′-dione (**IV**).

2 EXPERIMENTAL

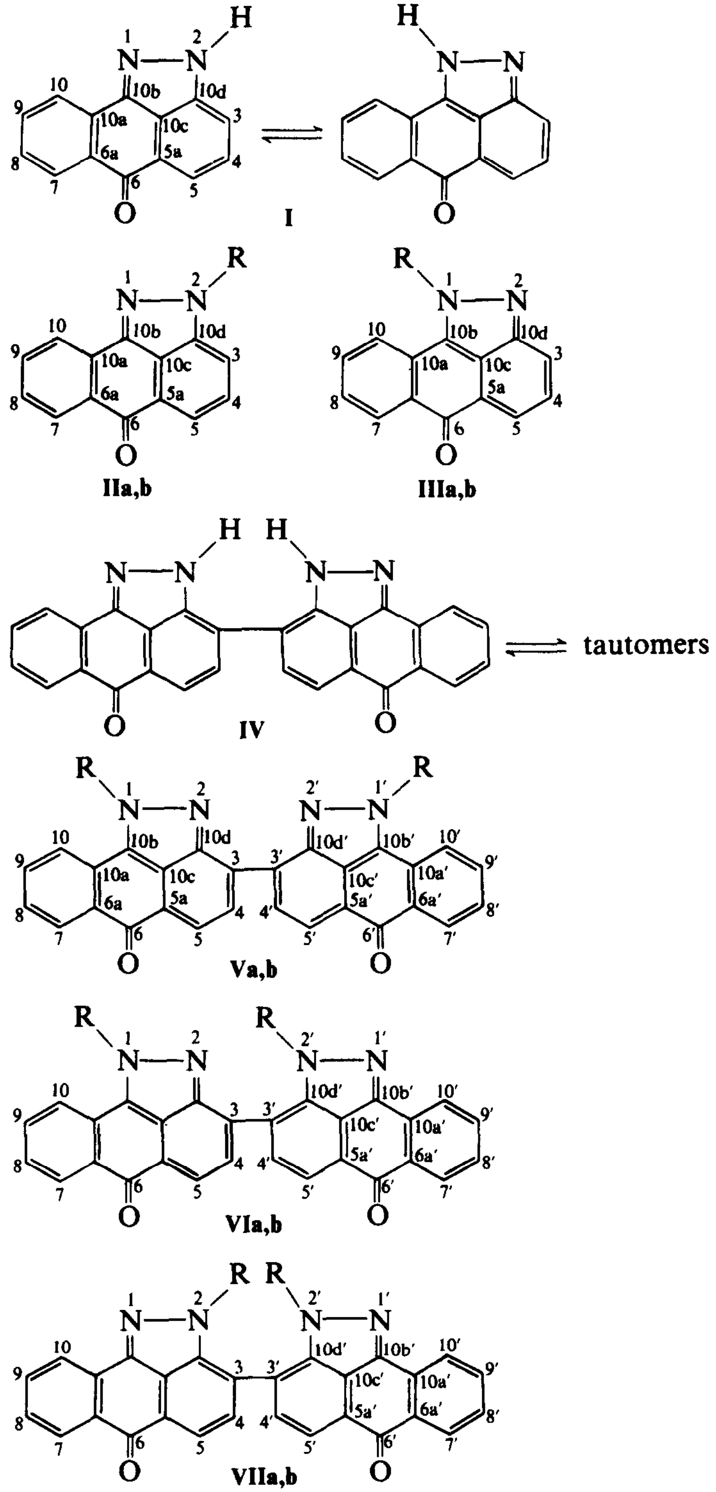
Pyrazoloanthrone (**I**) (Scheme 1) was a commercial product obtained from Hoechst (95·8% by polarography, m.p. 282°C). Bispyrazoloanthrone (**IV**) was prepared by alkali fusion[6] of pyrazoloanthrone, isolated in the form of a potassium salt and used for alkylation after drying and grinding.

2.1 Ethylation of the potassium salt of (anthra[1,9-*c*,*d*]pyrazol)-6-one (I)

To the solution of 3 g (0·013 mol) of **I** in 20 ml of pyridine, a solution of 2 g (0·036 mol) KOH in methanol was added and after 10 min the mixture was poured into 100 ml of toluene. The red potassium salt which separated was filtered, dried and added to 30 ml of dimethylformamide. After addition of 0·5 g KOH, 3·6 g (0·033 mol) of ethyl bromide was dropped in at 50–60°C. After 2 h the reaction mixture was cooled and diluted with water to give 3·2 g of a yellow compound (99%). This yellow compound was separated into two components by chromatography on an aluminium oxide (Reanal) column. The isomers were extracted with methanol and identified by NMR spectroscopy. Thin-layer chromatography data are given in Table 1.

1-Ethyl-(anthra[1,9-*c*,*d*]pyrazol)-6(1*H*)-one (**IIIb**): m.p. 162·5–164·0°C (143–144°C, Ref. 1), 38·4% of the original mixture.

2-Ethyl-(anthra[1,9-*c*,*d*]pyrazol)-6(2*H*)-one (**IIb**): m.p. 184·5–185·5°C (183·5–184·0°C, ref. 1), 61·6% of the original mixture.



Scheme 1. In the formulae, **a**: $R = CH_3$; **b**: $R = C_2H_5$.

TABLE 1
Thin-Layer Chromatography Data of Compounds **I**, **IIb**, **IIIb**, **VIb** and **VIIb**

Compound[a]	R_F	*Eluant*[b]
I	0·41	A
IIb	0·87	A
IIIb	0·65	A
VIb	0·34	B
VIIb	0·49	B

[a] For formulae see Scheme 1.

[b] A, Petroleum ether/acetone, 4:1; B, chlorobenzene/ethyl acetate, 4:1.

2.2 Ethylation of the dipotassium salt of IV

A suspension of 20·1 g of the dry ground dipotassium salt (65·3% by polarography), corresponding to 13·1 g (0·03 mol) of (3,3′-bianthra-[1,9-*c*,*d*]pyrazole)-6,6′-dione (**IV**) and 2·4 g of crushed KOH in 200 g of dry chlorobenzene was gradually treated with a solution of ethyl *p*-toluenesulphonate (19 g) in chlorobenzene/20 ml at 95°C. The mixture was then boiled for 3 h with distillation of 20 g of the liquor (b.p. 92–108°C). The product was filtered at 100°C, washed with 200 g of hot chlorobenzene and then dried to give 1,1′-diethyl-(3,3′-bianthra[1,9-*c*,*d*]pyrazole)-6,6′(1*H*,1′*H*)-dione (**Vb**) as an insoluble compound which did not melt until 400°C. The yield of crude product was 10·6 g (71·4%).

The filtrate was concentrated to afford 4·2 g of an orange–brown product. This was separated on an aluminium oxide column (Reanal) using toluene into two isomeric compounds, VIb and VIIb (for TLC data see Table 1),

> 1,2′-Diethyl-(3,3′-bianthra[1,9-*c*,*d*]pyrazole)-6,6′(1*H*,2′*H*)-dione (**VIb**): orange, m.p. 258·5–259·0°C, 68·2% content in the by-product mixture (yield, 2·86 g, corresponding to 19·2% of theory).

2,2′-Diethyl-(3,3′-bianthra[1,9-*c*,*d*]pyrazole)-6,6′(2*H*,2′*H*)-dione (**VIIb**), yellow, m.p. 286–287°C, 30·2% content in the by-product mixture (yield, 1·27 g, corresponding to 8·6% calculated with respect to the starting amount of compound **IV**).

2.3 NMR Spectroscopy

^{1}H- and ^{13}C-NMR spectra were measured at 400·13 MHz and 100·61 MHz, respectively, using a Bruker AM 400 spectrometer. The spectra were recorded for *ca.* 5% solutions or saturated solutions (in case of poor solubility) in deuteriochloroform (C^2HCl_3) at 300 K. The ^1H and ^{13}C chemical shifts were referred to internal tetramethylsilane ($\delta = 0{\cdot}00$). One-dimensional NMR spectra were measured in a standard manner at a digital resolution *ca.* 0·2 Hz/point (^1H) and 1 Hz/point (^{13}C). The selective INEPT spectra were measured according to Ref. 7. NOE Difference spectra and two-dimensional chemical shifts-correlated experiments were measured using the standard pulse sequences.[8]

NOE difference spectra: 5 mm tube, prescan saturation time 6 s, decoupler power level 45 dB below 0·2 W, separate free induction decays were accumulated for the on-resonance irradiations (NOEMULT[8]) and the control spectrum.

H,H-COSY (COSY[8]): 5 mm tube, relaxation time 2 s, 90° (^1H) = 10·5 μs; 90° mixing pulse, $F_1 = F_2 = 629{\cdot}7$ Hz or less, data matrix 512 × 256, eight scans during 128 time increments (zero filling in F_1); two dummy scans.

H,C-COSY (XHCORRDC[8]): 10 mm tube, relaxation time 2 s; 90° (^1H) = 9·7 μs; 90° (^{13}C) = 8·5 μs; polarisation time = refocusing time = 3·1 ms; $F_1 = 629{\cdot}7$ Hz or less, $F_2 = 1538{\cdot}5$ Hz or less, data matrix 1024 × 128; from eight to 32 scans during 64 time increments (zero filling in F_2; two dummy scans.

The mass spectra were obtained on a JEOL JMS 01 SG-2 mass spectrometer. Operating conditions were as follows: ionisation energy 75 eV, emission current 200 μA, accelerating voltage 8 kV, source temperature 260°C, normal resolution $R_{10\%} = 1000$. All samples were introduced with a direct insertion probe.

3 RESULTS AND DISCUSSION

The ^1H and ^{13}C chemical shifts in the compounds **IIb**, **IIIb**, **VIb** and **VIIb** in deuteriochloroform at 300 K are shown in Table 2. Assignment of the ^1H and ^{13}C chemical shifts in these compounds was based on analysis of one- and two-dimensional NMR spectra[9,10] (NOE difference spectra,[11] selective INEPT,[7] H,H-COSY,[9,10] H,C-COSY[9,10]).

Homonuclear shift-correlated spectra (H,H-COSY) of compounds **IIb** and **IIIb** were measured first and proton–proton connectivity of four- and three-proton spin systems was obtained in both the compounds: **IIb**: 8·36–7·45–7·62–8·09 and 7·89–7·49–7·54; **IIIb**: 8·48–7·47–7·67–7·81 and 8·06–7·59–8·01, respectively.

After measurement of the selective INEPT spectra[7] via ^3J(CH) by transfer from the protons with $\delta(^1H) = 8{\cdot}36$ and 7·89 (**IIb**) and $\delta(^1H) = 8{\cdot}48$ and 8·06 (**IIIb**), respectively, carbonyl group signals were observed and thus, the proton signals must correspond to H(7) and H(5).

Ethyl group position determination was carried out using difference nuclear Overhauser effect (NOE) spectroscopy.[11] NOE difference spectroscopy has become a familiar tool for making connections between nuclei through space. In principle, a control ('normal') spectrum (Fig. 1a) is subtracted from one containing double resonance effect and, ideally, the responses caused by nuclear Overhauser effect enhancement (corresponding to the space proximity of nuclei) are visible and unaffected signals are missing (Fig. 1b,c).

NOE difference spectra were measured with compounds **IIb** and **IIIb**, irradiating quartets of NCH_2 groups. In **IIb**, NOE enhancement was observed for a proton with $\delta(^1H) = 7{\cdot}54$ (a part of the three spin system–*vide ultra*) and, hence the ethyl group is bonded to N(2), whilst in **IIIb**, NOE enhancement was detected for a proton with $\delta(^1H) = 7{\cdot}81$ (a part of the four-spin system) which corresponds to the fact that the ethyl group must be on N(1). The assignment of $\delta(^1H)$ of H(3) in **IIb** and that of H(10) in **IIIb** was mutually corroborated both from selective INEPT spectra (taking in account the results from H,H-COSY and H,C-COSY) and NOE difference spectra.

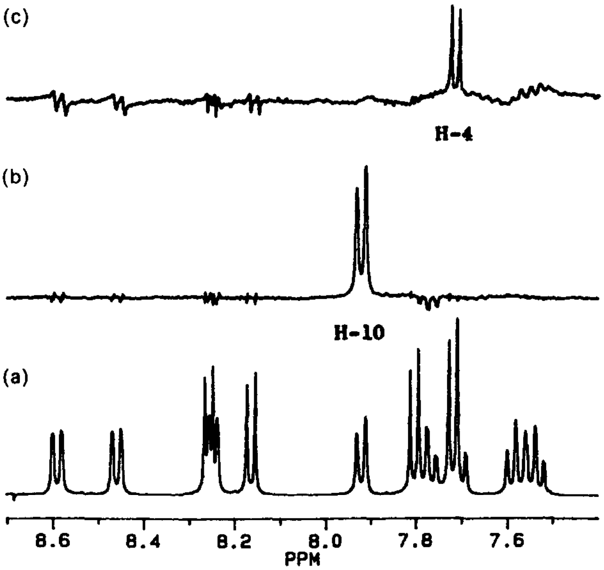


Fig. 1. (a) Aromatic part of the ^{1}H-NMR spectrum of **VIb** in deuteriochloroform; (b) NOE difference spectrum arising from irradiation of $N(1)CH_2$ ($\delta = 4{\cdot}90$); and (c) NOE difference spectrum arising from irradiation of $N(2')CH_2$ ($\delta = 4{\cdot}11$).

TABLE 2

^{1}H and ^{13}C Chemical Shifts in Compounds **IIb**, **IIIb**, **VIb** and **VIIb** in Deuteriochloroform

H/C no.	*Compound*							
	IIb		**IIIb**		**VIb**[a]		**VIIb**[b]	
	^{1}H	^{13}C	^{1}H	^{13}C	^{1}H	^{13}C	^{1}H	^{13}C
CH_3	1·56	15·37	1·71	15·42	1·69 (1·14)	15·53 (15·53)[c]	1·08	15·62[c]
NCH_2	4·46	44·76	4·88	48·80	4·90 (4·11)[c]	49·02 (46·30)[c]	4·01; 3·81[d]	45·90
3	7·54	114·57	8·01	124·06	— —	123·35 (127·07)	—	125·89
4	7·49	127·90	7·57	127·97	7·71 (7·80)	129·19 (130·93)	7·67	130·19
5	7·89	120·37	8·06	123·43	8·25 (8·15)	123·35 (121·01)	8·15	120·60
5a	—	126·14	—	126·48	— —	[e] [e]	—	126·91
6	—	183·51	—	182·93	— —	182·74 (183·70)	—	183·41
6a	—	133·04	—	132·73	— —	[f] [f]	—	133·14
7	8·36	128·94	8·48	130·40	8·58 (8·45)	130·63 (129·08)	8·47	129·22
8	7·45	127·90	7·47	127·64	7·57 (7·53)	128·15 (128·30)	7·56	128·66
9	7·26	133·09	7·67	133·17	7·77 (7·70)	133·51 (133·28)	7·73	133·49
10	8·09	122·44	7·81	122·00	7·91 (8·23)	122·29 (122·71)	8·24	122·84
10a	—	131·73	—	128·18	— —	128·09 (131·81)	—	131·59
10b	—	138·28	—	127·64	— —	127·07 (138·96)	—	139·28
10c	—	123·44	—	123·00	— —	[f] (124·74)	—	124·19
10d	—	138·28	—	145·94	— —	145·21 (137·13)	—	137·20

[a] Chemical shifts in parentheses correspond to $\delta(^{1}H(i'))$ and $\delta(^{13}C(i')$ (see Scheme 1).

[b] Chemical shifts of $\delta(^{1}H(i'))$ and $\delta(^{13}C(i'))$ are equal to $\delta(^{1}H(i))$ and $\delta(^{13}C(i))$, respectively, because of the symmetry of **VIIb**.

[c] Chemical shifts of $N(2')CH_2CH_3$.

[d] Prochiral protons (see text).

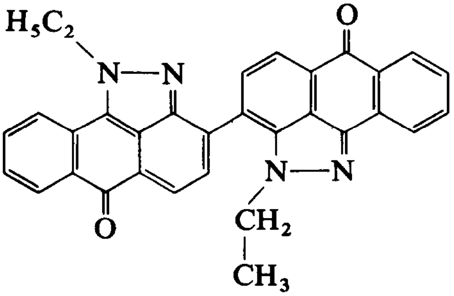
[e] 126·79 or 126·48.

[f] 133·81 or 133·08 or 132·73.

The ^{13}C chemical shifts of carbons bearing proton(s) were assigned after measurement of heteronuclear shift-correlated spectra[9] (H,C-COSY) and $\delta(^{13}C)$ of quaternary carbons were determined after analysis of a set of selective INEPT spectra via $^3J(CH)$ (Table 2).

H,H-COSY of **VIIb** revealed signals of four- and two-spin systems (Table 2), i.e. this compound must be symmetrical from the point of view of the position of the ethyl groups. Because no reasonable NOE enhancement of aromatic protons was observed in the NOE difference spectrum, protons of NCH_2 groups being irradiated, the ethyl groups must be bonded to nitrogens N(2) and N(2'). The protons of NCH_2 groups are prochiral[12] [$\delta(^1H) = 4{\cdot}01(1H)$; $3{\cdot}81(1H)$; $^2J(HCH) = 14{\cdot}2$ Hz; $^3J(HCCH_3) = 7{\cdot}1$ Hz]. The ^{13}C chemical shifts in **VIIb** were assigned as described above.

The H,H-COSY spectrum of **VIb** consisted of two four- and two two-spin systems; hence, this compound is asymmetrical and the ethyl groups are bonded to N(1) and N(2'). NOE difference enhancement at $\delta(^1H) = 7{\cdot}91$ (H(10)—Fig. 1b) represented the starting fix point for analysis of the ^1H and ^{13}C chemical shifts using H,H-COSY; H,C-COSY and selective INEPT spectra. Figure 1c shows the NOE difference spectrum arising from irradiation of protons $N(2')CH_2$ [$\delta(^1H) = 4{\cdot}11$]. A NOE effect was observed on proton H(4) [$\delta(^1H) = 7{\cdot}71$]. From this it follows that protons $N(2')CH_2$ and H(4) are close to each other and, thus, formula **VIII** represents better the conformational preference of compound **VIb** than that shown in Scheme 1.



VIII

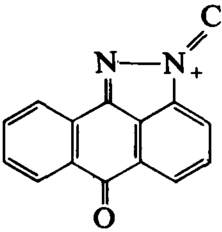
Compound **Vb** is extremely insoluble and its NMR spectra cannot be measured. The structure of **Vb** follows from the fact that this compound represents the third possibility for the positions of the two ethyl groups (compare with **VIb** and **VIIb**) and it can be prepared from the isolated pure compound **IIIb**, of which the ethyl group position was determined experimentally (*vide ultra*).

Mass spectra results obtained with measured compounds are summarised in Table 3. The EI spectra of compounds **II**–**VII** show stable molecular ions (for pyrazoloanthrone and bispyrazoloanthrone, derivatives were detected

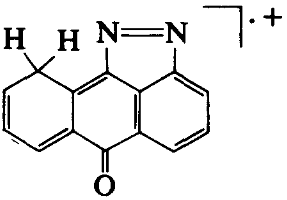
TABLE 3
Relative Abundance of Selected Ions in Mass Spectra of Compounds **IIb–VIIb**

Compound	$[M^{+}]$	$[(M-CH_3)^{+}]$	$[(M-C_2H_4)^{+\cdot}]$	$[(M-CH_3-C_2H_4)^{+}]$	$[(M-C_2H_4-C_2H_4)^{+\cdot}]$	$[M^{2+}]$
IIb	71	100	5	4	2	4
IIIb	69	8	100	—	5	2
Vb	100	19	73	9	32	10
VIb	13	100	2	7	2	6
VIIb	93	100	4	17	4	11

at 248 and 494 Da, respectively) and intense fragments for $(M-CH_3)^+$, $(M-C_2H_4)^{+\cdot}$, $(M-CH_3-C_2H_4)^+$, $(M-C_2H_4-C_2H_4)^{+\cdot}$. Intensities of the double-charged molecular ions were also relatively strong. For identification of the compounds, $(M-CH_3)^+$ and $(M-C_2H_4)^+$ fragmentations were the most important. The former fragmentation (loss of a methyl radical from the molecular ion with formation of cation **IX**) was typical of $N(2)-C_2H_5$ derivatives. On the other hand, $N(1)-C_2H_5$ derivatives produce the $(M-C_2H_4)^{+\cdot}$ radical cation **X** as the most abundant ion of the spectra. These fragmentation pathways, both loss of methyl radical and McLafferty rearrangement, were also observed in symmetrical bispyrazoloanthrone derivatives.



IX



X

The spectrum of **VIb** showed a different pattern. The molecular ion was weaker and in the molecular region only a strong ion due to loss of the methyl radical was observed. Elimination of a molecule of C_2H_4 with hydrogen transfer (an expected mechanism of competition in this asymmetrical compound) was suppressed. These results are in agreement with NMR observations, where a different conformation of **VIb** (**VIII**) is suggested in comparison with compounds **Vb** and **VIIb**. This difference results probably in an unexpected course of the fragmentation without competition of the mechanisms discussed above, viz. β-cleavage was preferred, leading to a more stable cation than that of the McLafferty rearrangement with production of a radical cation species.

4 CONCLUSIONS

We have determined unambiguously the constitutions of two *N*-ethyl derivatives of pyrazoloanthrone and two soluble by-products of the bisalkylation of bispyrazoloanthrone. The orange compound corresponds (contrary to the conclusions in Refs 1 and 2) to **VIb** and the yellow one to **VIIb**. The constitution of Vat Red 13 (CI 70320) has been determined indirectly.

REFERENCES

1. Maki, T. & Takamatsu, T., *J. Chem. Soc. Japan, Ind. Chem. Sect.*, **54** (1951) 281.
2. Maki, T. & Takamatsu, T., *J. Chem. Soc. Japan, Ind. Chem. Sect.*, **54** (1951) 326.
3. Anon., *Colour Index*, 3rd edn., Society of Dyers and Colourists, Bradford, 1971.
4. Bradley, W. & Geddes, K. W., *J. Chem. Soc.* (1952) 1036.
5. Bradley, W. & Bruce, C. S., *J. Chem. Soc.* (1954) 1894.
6. Havlíčková, L., Koloničný, A., Capoušková, L. & Havlıček, J., Czech. Patent 202 939.
7. Bax, A., *J. Magn. Reson.*, **57** (1984) 314.
8. Bruker Software Library, DISN 85 (1985).
9. Morris, G. A., *Magn. Reson. Chem.*, **24** (1986) 371.
10. Ernst, R. R., Bodenhausen, G. & Wokaun, A., *Principles of Nuclear Magnetic Resonance in One and Two Dimensions.* Clarendon Press, Oxford, 1987.
11. Sanders, J. K. M. & Mersh, J. D., *Progr. NMR Spectr.*, **15** (1982) 353.
12. Jennings, W. B., *Chem. Rev.*, **75** (1975) 307.