aldehyde, it was necessary to use a large amount of **8c** (up to 10 g) and a large volume (150 mL) of acetonitrile and to add the phosphonium salt in small portions over at least 24 h. When TLC indicated that all yellow monoaldehyde was converted, the volume was reduced to half and the same workup procedure was followed.

10c: yield 1.90 g (88%) of violet crystals; mp 188 °C; IR (KBr) ν (cm^{-1}) 1729, 1586, 1434, 1263; ^{1}H-NMR (CDCl$_3$) δ 6.32 (2 H, s), 6.28 (2 H, s), 3.83 (6 H, s), 3.82 (6 H, s), 3.42 (3 H, s); MS *m/e* (%) 541 (M$^+$, 100), 483 (78), 381 (19), 366 (18). Anal. Calcd for $C_{21}H_{19}NO_8S_4$: C, 46.58; H, 3.51; N, 2.59; S, 23.66. Found: C, 46.61; H, 3.51; N, 2.64; S, 23.69.

11c: yield 2.09 g (99%) of brown crystals; mp 89 °C; IR (KBr) ν (cm^{-1}) 1741, 1588, 1434, 1263, 1030; ^{1}H-NMR (CDCl$_3$) δ 6.43 (2 H, s), 6.32 (2 H s), 3.97 (6 H, s), 3.96 (6 H, s); MS *m/e* (%) 528 (M$^+$, 100), 470 (5), 354 (11), 264 (8). Anal. Calcd for $C_{20}H_{16}O_9S_4$: C, 45.45; H, 3.03; S, 24.24. Found: C, 45.53; H, 2.82; S, 24.00.

12c: yield 1.98 g (91%) of brown crystals; mp 149 °C; IR (KBr) ν (cm^{-1}) 1731, 1585, 1434, 1260; ^{1}H-NMR (CDCl$_3$) δ 6.81 (2 H, s), 6.58 (2 H, s), 3.87 (6 H, s), 3.87 (6 H, s); MS *m/e* (%) 544 (M$^+$, 100), 486 (5), 370 (19), 272 (6). Anal. Calcd for $C_{20}H_{16}NO_8S_4$: C, 44.12; H, 2.94; S, 29.41. Found: C, 44.59; H, 3.02; S, 28.90.

11a via Decarbomethoxylation of 11c (Scheme III). In a 25-mL round-bottomed flask were placed **11c** (0.53 g, 0.001 mol), LiBr, H_2O (0.46 g, 0.0011 mol), and 5 mL of HMPA (no purification). The mixture was heated to 90 °C in an oil bath, and the reaction was monitored by TLC. Initially several spots (staining green with iodine) appeared. When only one was left (ca. 50–70 min), the temperature was increased to 150 °C and maintained (70–80 min) until TLC showed only one clear yellow spot (staining reddish-brown with iodine). The reaction mixture was poured into 100 mL of water, and the resulting mixture was extracted with 3 × 50 mL of methylene chloride. The combined extracts were washed with 2 × 25 mL of sodium chloride solution and once with 25 mL of water, then dried with $MgSO_4$, treated with a little decolorizing carbon, and filtered. The methylene chloride was evaporated to afford **11a** (66 mg, 23%).

TCNQ Complexes. The complexes were synthesized by mixing a concentrated solution of the donor in acetonitrile with a solution containing an excess of TCNQ in acetonitrile. Immediately, a dark solution resulted, from which the analytically pure TCNQ complex separated. Anal. Calcd for (**10c**)$_2$(TCNQ), $C_{54}H_{42}O_{16}N_6S_8$: C, 50.38; H, 3.27; N, 6.53. Found: C, 50.43; H, 3.29; N, 6.98. Calcd for (**11a**)$_2$(TCNQ)$_3$, $C_{60}H_{28}O_2N_{12}S_8$: C, 59.80; H, 2.32; N, 13.95; S, 21.26. Found: C, 59.53; H, 2.37; N, 13.39; S, 21.19.

Acknowledgment. This work was supported by a grant from the National Science Foundation (CHE-9001714). We also wish to thank the Forskerakademiet, Denmark, for a travel grant to T.K.H.

Registry No. **8c**, 68629-95-8; **9a**, 37893-28-0; **9b**, 823-82-5; **9c**, 932-95-6; **10a**, 141198-28-9; **10b**, 141198-29-0; **10c**, 141198-30-3; **10c**·$^1/_2$TCNQ, 141198-36-9; **11a**, 141198-31-4; **11a**·$^3/_2$TCNQ, 141198-37-0; **11b**, 141250-91-1; **11c**, 141198-32-5; **12a**, 141198-33-6; **12b**, 141198-34-7; **12c**, 141198-35-8; **13a**, 133113-76-5; **13b**, 133186-66-0.

New Ultraviolet Stabilizers: 3- and 5-(2′-Hydroxyphenyl)pyrazoles

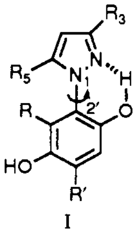
Javier Catalán,*,[†] Fernando Fabero,[†] Rosa M. Claramunt,*,[‡] M. Dolores Santa Maria,[‡] M. de la Concepción Foces-Foces,[§] Felix Hernández Cano,[§] Martín Martínez-Ripoll,[§] José Elguero,[‖] and Roberto Sastre[⊥]

Contribution from the Departamento de Química Física Aplicada, Facultad de Ciencias, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain, Departamento de Química Orgánica y Biología, UNED, 28040 Madrid, Spain, U.E.I. de Cristalografía, Instituto de Química Física "Rocasolano", CSIC, 28006 Madrid, Spain, Instituto de Química Médica, CSIC, 28006 Madrid, Spain, and Instituto de Ciencia y Tecnología de Polímeros, CSIC, 28006 Madrid, Spain. *Received October 11, 1991*

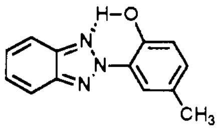
Abstract: A new class of ultraviolet stabilizers, the *C*-(2′-hydroxyphenyl)pyrazoles, is described. The combined use of X-ray crystallography [3(5)-(2′-hydroxyphenyl)pyrazole (**5**), 1-methyl-3-(2′-hydroxyphenyl)pyrazole (**7**), and 1-methyl-5-(2′-hydroxyphenyl)pyrazole (**8**)], NMR (^{1}H and ^{13}C), and UV spectroscopies allows the determination of the major tautomers, the coplanarity of both rings if present, and the existence of hydrogen bonds. Compounds **5** and **7**, in which there is an intramolecular hydrogen bond (IMHB), do not fluoresce in cyclohexane. Solvent and temperature experiments prove that for these compounds in cyclohexane proton transfer took place in the excited singlet state but not in the triplet state (phosphorescence) and that the latter one is of higher energy than the former. The fact that the absorptions of planar 1-methyl-3-(2′-methoxyphenyl)pyrazole (**9**) and nonplanar 1-methyl-5-(2′-methoxyphenyl)pyrazole (**10**) are quite different whereas their emissions are very similar suggests that **10** might behave as a laser dye in the UV region (from an excited planar form to a ground state nonplanar form). Finally, the photostability of (2′-hydroxyphenyl)- and (2′-methoxyphenyl)pyrazoles was determined, compound **7** being even more stable than Tinuvin P.

Introduction

In previous papers,[1,2] we have discussed the photostability of some *N*-(2′-hydroxyphenyl)pyrazoles (general formula I) and their application to photoprotection of polystyrene. Some of these compounds show low emission quantum yields and a high stability to ultraviolet light. However, the radiationless deactivation of the absorbed ultraviolet energy could not be explained as being



I



Tinuvin P

---

* Authors to whom correspondence should be addressed.

[†] Departamento de Química, UAM.

[‡] Departamento de Química Orgánica y Biología, UNED.

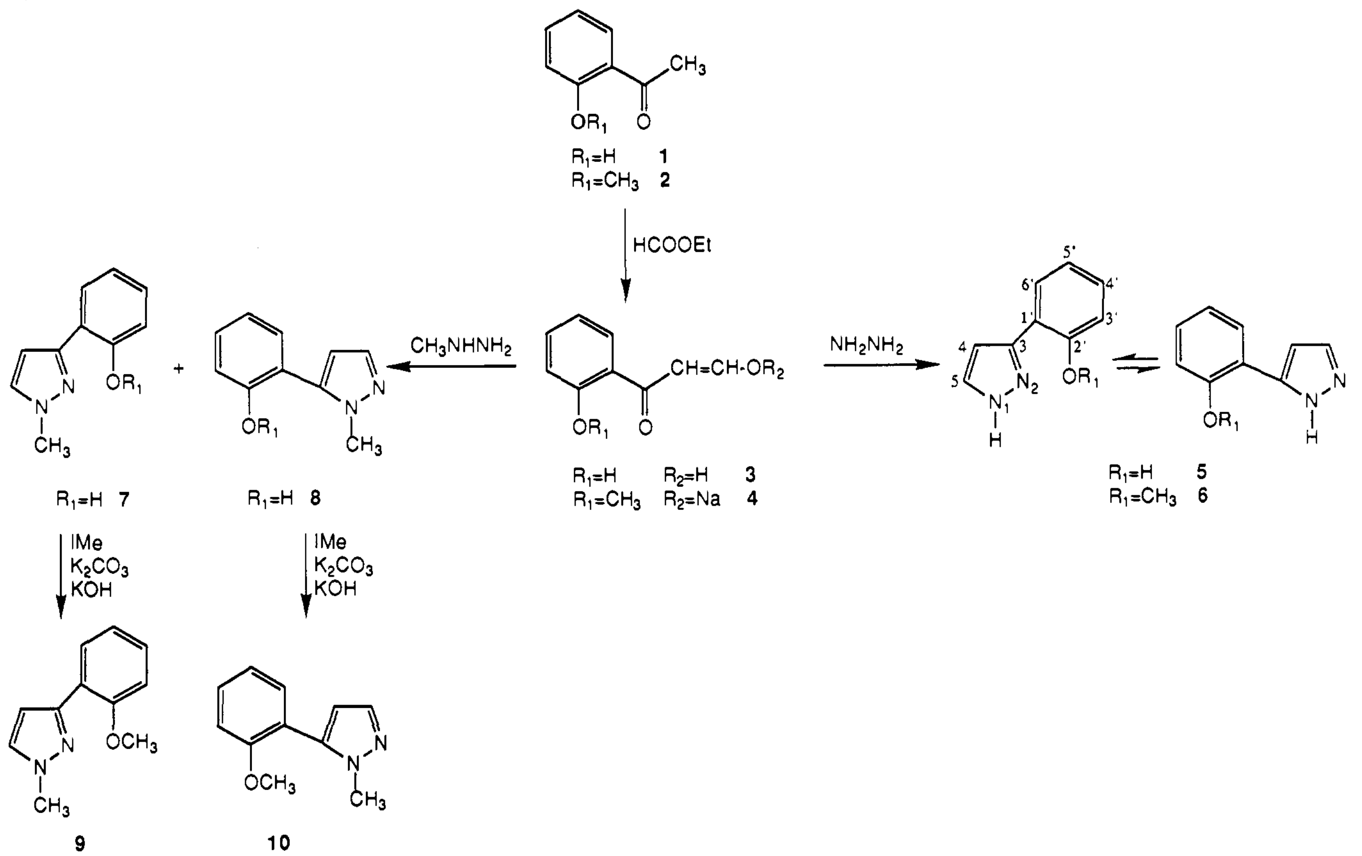
[§] Instituto Rocasolano, CSIC.

[‖] Instituto de Química Médica, CSIC.

[⊥] Instituto de Ciencia y Tecnología de Polímeros, CSIC.

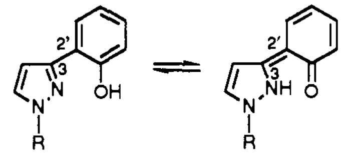
0002-7863/92/1514-5039$03.00/0 © 1992 American Chemical Society

Scheme I

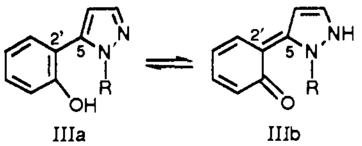


exclusively due to an excited-state intramolecular proton transfer (ESIPT), i.e., of the phenolic proton to one of the pyrazole nitrogen atoms via the intramolecular hydrogen bond (IMHB). Instead we suggested that this dissipation of energy may also be facilitated by torsional motions of the 2′-hydroxyphenyl group about the N1–C2′ bond in the excited singlet state. Indeed several authors[3-5] have proposed that similar torsional motions (about the central N2–C2′ bond) are responsible for the radiationless dissipation of energy in the case of 2-(2′-hydroxy-5′-methylphenyl)benzotriazole (Tinuvin P).

As a part of a systematic study of the photophysical properties of ultraviolet stabilizers[6] we report here the photophysical behavior of the related 3- and 5-(2′-hydroxyphenyl)pyrazoles (IIa, R = H; IIIa, R = H) and of some of their *N*- and *O*-methyl derivatives.



IIa IIb



IIIa IIIb

It would be expected that conjugation would exist between the two rings of the parent phenols (IIa and IIIa) and that therefore rotation of the aryl group about the C3–C2′ and the C5–C2′ bond, respectively, would be restricted. Furthermore, for both phenols, existence of the quinonoid tautomers, IIb and IIIb, respectively, is feasible and therefore energy dissipation via the ESIPT mechanism could occur, particularly in the case of phenol IIa, R = H, and its 1-methyl derivative IIa, R = Me.

For this investigation, we have synthesized phenol IIa, R = H, **5**, and a set of its methylated derivatives, **6**–**10**, via the intermediates **1**–**4** (see Scheme I), for the purpose of answering the following questions, which arose out of our earlier work: (i) Are compounds with a central carbon–carbon bond (and not a nitrogen–carbon bond as in structure I) photostable? (ii) What role does an IMHB (if present) play in the photophysical properties of such compounds?

Experimental Section

General Methods. Melting points are uncorrected. Infrared spectra (KBr disks) were obtained on a Bomem DA3 instrument. Mass spectra were obtained on a Hewlett-Packard GC/MS 5985 spectrometer and nuclear magnetic resonance spectra on a Bruker AC-200 spectrometer. Chemical shifts and coupling constants were measured in deuteriochloroform or hexadeuteriodimethyl sulfoxide with tetramethylsilane as internal standard. ^{1}H and ^{13}C chemical shifts are accurate to 0.01 and 0.1 ppm, respectively; coupling constants are accurate to ±0.2 Hz (^{1}H NMR) and to ±0.6 Hz (^{13}C NMR). The data acquisition parameters for the heteronuclear (^{1}H–^{13}C) correlation experiment were set as follows: F_1 domain (SI1, 512 W; SW1, 1403.7 Hz; relaxation delay D1, 3 s), F_2 domain (SI2, 4K; SW2, 10000 Hz), number of transients per FID, NS, 32; number of preparatory dummy transients per FID, DS, 0. The 2D experiment was processed with a sine bell window (WDW1 = WDW2 = S, SSB1 = 0, SSB2 = 2). Analytical thin-layer chromatography was performed on silica gel Merck Kieselgel 60 F254 with a layer thickness of 0.2 mm. Column chromatography was carried out with silica gel Merck 60 (70-230 mesh, ASTM).

Synthesis (see Scheme I). 2-Hydroxy-α-(hydroxymethylene)acetophenone (**3**) was prepared by reaction of *o*-hydroxyacetophenone (**1**) and ethyl formate in the presence of sodium as described in the literature.[7]

---

(1) Catalán, J.; Fabero, F.; Guijarro, M. S.; Claramunt, R. M.; Santa Maria, M. D.; Foces-Foces, M. C.; Cano, F. H.; Elguero, J.; Sastre, R. *J. Am. Chem. Soc.* **1990**, *112*, 747; **1991**, *113*, 4046.

(2) Sastre, R.; Catalina, F.; Mateo, J. L.; Claramunt, R. M.; Santa Maria, M. D.; Catalán, J. *J. Polym. Sci.: Part A; Polym. Chem.* **1990**, *28*, 3661.

(3) Huston, A. L.; Scott, G. W. *Proc. Soc. Photo-Opt. Instrum. Eng.* **1982**, *322*, 215.

(4) Bocian, D. F.; Huston, A. L.; Scott, G. W. *J. Chem. Phys.* **1983**, *79*, 5802.

(5) O'Connor, D. B.; Scott, G. W.; Coulter, D. R.; Gupta, A.; Webb, S. P.; Yeh, S. W.; Clark, J. H. *Chem. Phys. Lett.* **1985**, *121*, 417.

(6) Catalán, J.; Pérez, P.; Fabero, F.; Wilshire, J. F. K.; Claramunt, R. M.; Elguero, J. *J. Am. Chem. Soc.* **1992**, *114*, 964.

(7) Schönberg, A.; Sina, A. *J. Am. Chem. Soc.* **1950**, *72*, 3396.

3(5)-(2′-Hydroxyphenyl)pyrazole (5). To an ice-cooled stirred solution of 2 g (12 mmol) of 2-hydroxy-α-(hydroxymethylene)acetophenone (3) in 3.5 mL of anhydrous methanol was added 0.6 g (19 mmol) of hydrazine (100%). After the addition was completed, the reaction mixture was heated in a water bath for 1 h and then poured into ice. The resulting precipitate was filtered off and dried to yield the compound **5** (1.5 g, 80%) as a white crystalline solid, mp 84–86 °C (from water) (lit.[8] mp 98–99 °C). IR 3411–3050 (NH), 3014–2336 cm^{-1} (OH); MS (Th, relative intensity) 174 ($M^{\bullet +}$, 100).

3(5)-(2′-Methoxyphenyl)pyrazole (6). 2-Methoxyacetophenone (2) (0.97 g, 6.5 mmol) and ethyl formate (0.72 g, 9.9 mmol) were added in one portion with rapid stirring to a slurry of sodium methoxide (0.35 g, 6.5 mmol) in 5 mL of toluene. The thick slurry was stirred for 2 h and the resulting precipitate of 2-methoxy-α-(sodiooxymethylene)acetophenone (4) filtered off, washed with hot toluene followed by hexane, and then dried. To a slurry of this solid in 5 mL of methanol was added a solution of hydrazine monohydrochloride (0.44 g, 6.5 mmol) in 5 mL of water. After standing overnight at room temperature, the resultant solution was extracted with dichloromethane. Removal of solvent from the dried ($MgSO_4$) extract gave the ether **6** initially as an oil, which subsequently crystallized from a mixture of chloroform and hexane. Mp 85–86 °C, 65% yield; IR 3411–3040 cm^{-1} (NH); MS (Th, relative intensity) 174 ($M^{\bullet +}$, 100). Anal. Calcd for $C_{10}H_{10}N_2O$: C, 68.95; H, 5.79; N, 16.08. Found: C, 68.58; H, 5.75; N, 16.05.

1-Methyl-3-(2′-hydroxyphenyl)pyrazole (7) and 1-Methyl-5-(2′-hydroxyphenyl)pyrazole (8). To a stirred solution of 1.0 g (6.1 mmol) of 2-hydroxy-α-(hydroxymethylene)acetophenone (3) in 5 mL of ethanol was added 0.45 g (9.7 mmol) of methylhydrazine. The mixture was then heated under reflux for 4 h. On cooling, the solvent was evaporated under vacuum, and the crude residue was separated into its components, *N*-methylpyrazoles **7** and **8** (R_f values 0.64 and 0.23, respectively), with chloroform/ethanol (95/5) as eluent. Compound **7** (56% yield) had mp 84–85 °C (lit.[9] mp 80–82 °C); IR 3300–2400 cm^{-1} (OH); MS (Th, relative intensity) 174 ($M^{\bullet +}$, 100). Compound **8** (25% yield) had mp 167–168 °C (lit.[9] mp 165–167 °C); IR 3300–2200 cm^{-1} (OH); MS (Th, relative intensity) 174 ($M^{\bullet +}$, 100).

1-Methyl-3-(2′-methoxyphenyl)pyrazole (9) and 1-Methyl-5-(2′-methoxyphenyl)pyrazole (10). A mixture of 0.5 g (2.87 mmol) of *N*-methylpyrazole (**7** or **8**), 1.2 g (8.6 mmol) of anhydrous K_2CO_3, 0.3 g (5.75 mmol) of KOH, and 0.21 mL (3.45 mmol) of CH_3I in 5 mL of anhydrous acetone was heated under reflux for 24 h. After cooling, the solvent and excess of CH_3I were evaporated under reduced pressure to give methoxy derivatives **9** or **10**, respectively. Compounds **9** and **10** were purified by column chromatography using as the eluent chloroform/ethanol (95/5) and isolated as oils in quantitative yields. Compound **9**: R_f 0.56; MS (Th, relative intensity) 188 ($M^{\bullet +}$, 100). Compound **10**: R_f 0.53; MS (Th, relative intensity) 188 ($M^{\bullet +}$, 100).

Crystal Structure Determinations. 3(5)-(2′-Hydroxyphenyl)pyrazole (**5**) was crystallized from a mixture of water–ethanol, 1-methyl-3-(2′-hydroxyphenyl)pyrazole (**7**), and 1-methyl-5-(2′-hydroxyphenyl)pyrazole (**8**) from chloroform–hexane. Our attempts to crystallize compound **6** as single crystals were unsuccessful; twin crystals were obtained from all attempts.

Crystal Data. **5**: $C_9H_8N_2O$, M = 160.18, monoclinic, $P2_1/c$, a = 15.1329 (5) Å, b = 5.5941 (1) Å, c = 19.4777 (9) Å, β = 110.874 (3)°, D_c = 1.381 g·cm^{-3}, Z = 8 (two independent molecules). Cell constants were obtained from a least-squares fit from the position of 78 reflections with θ = 45°, for Cu Kα radiation. A transparent, colorless prismatic sample (dimensions 0.50 × 0.20 × 0.17 mm) was used for the analysis.

7: $C_{10}H_{10}N_2O$, M = 174.20, monoclinic, $P2_1/n$, a = 12.3779 (6) Å, b = 12.2980 (7) Å, c = 5.9815 (2) Å, β = 96.055 (5)°, D_c = 1.278 g·cm^{-3}, Z = 4. Cell constants from 54 reflections with θ = 45° for Cu Kα. A transparent prism (dimensions 0.27 × 0.20 × 0.13 mm) was sealed within a capillary tube in order to prevent decomposition by air.

8: $C_{10}H_{10}N_2O$, M = 174.20, monoclinic, $P2_1/a$, a = 13.3353 (6) Å, b = 11.2320 (5) Å, c = 6.2678 (2) Å, β = 90.402 (4)°, D_c = 1.233 g·cm^{-3}, Z = 4. Cell constants from 72 reflections with θ = 45° for Cu Kα. Transparent prism (dimensions 0.47 × 0.10 × 0.07 mm).

Data collection for the three compounds was obtained with the following equipment and conditions: Philips PW1100 diffractometer, Cu Kα radiation, graphite monochromator, $\omega/2\theta$ scans, bisecting geometry, 1 × 1° as detector apertures, 1.5° scan width, 1 min/reflection, but 0.5 min/reflection for compound **7**; good stability over the data collection period, checked every 90 min by means of two standard reflections. Compound **5**: A total of 3003 collected reflections, giving rise to 2631 independent ones and to 2177 observations with a 3σ(I) criterion. Compound **8**: 1849, 1600, and 1253 reflections, respectively, with a 3σ(I) criterion. Compound **7**: 1779, 1501, and 936 reflections, respectively, with a 3σ(I) criterion. No absorption corrections were considered necessary, the linear coefficients being 7.21, 6.28, and 6.51 cm^{-1}, respectively.

Structure Solution and Refinement. All structures were solved by direct methods[10] and refined by full-matrix least-squares procedures on F_{obs}. All hydrogen atoms were located on a difference synthesis and refined isotropically. Empirical weighting schemes were used so as to give no trends in $\langle w\Delta^2F\rangle$ when analyzed versus $\langle |F|\rangle$ or $\langle \sin\theta/\lambda\rangle$. The final residual synthesis shows no peaks higher than 0.27, 0.17, and 0.20 eÅ^{-3}, respectively. Final shift/error were 0.24, 1.40, and 0.60. The highest thermal factors are $U22$ (C3A) = 0.066 (2), $U33$ (C9) = 0.082 (2), and $U33$ (C9) = 0.137 (2) Å^2, respectively. Final R and R_w factors were 0.054, 0.067; 0.045, 0.044; and 0.064, 0.066 for each of the three compounds. The resulting fractional atomic coordinates for the non-hydrogen atoms are given as Supplementary Material. Most of the calculations were done with the X-RAY System[11] on a VAX 11/750 computer. The atomic scattering factors were taken from the International Tables.[12]

Fluorescence and Phosphorescence Measurements. Room-temperature absorption spectra were obtained with a Perkin-Elmer 554 and a Shimadzu UV-2100.

Fluorescence spectra at room temperature and at 77 K corrected for the instrumental sensitivity were measured with an SLM 48000 S spectrofluorometer by using a cooled wide band rf housing for the R928 photomultiplier tube. Corrected excitation spectra were obtained with constant excitation intensity controlled by rhodamine B as a quantum counter, and optical densities were measured in the excitation zone range of 0.02 unless specified. Emission quantum yields in ethanol (EtOH), dimethyl sulfoxide (DMSO), and acetonitrile (ACN) were determined relative to that of 1,4-dihydroxy-2,5-bis(pyrazol-1′-yl)benzene (**11**)[1] and in cyclohexane (CyH) relative to 1-methyl-2-phenylbenzimidazole.[13]

Phosphorescence spectra, corrected for instrumental sensitivity, were measured with an SLM 48000 S instrument using the SLM modified accessory. Low-temperature emission studies were carried out employing a liquid nitrogen accessory to cool the samples to temperatures approaching 77 K.

A UV-accelerometer device was employed for the study of the photostability of the above compounds. The UV source consists of eight fluorescent tubes (Philips TL-40W/12) that have a wavelength range of 260–390 nm with maximum at 310 nm. The lamps are arranged vertically on the circumference of a drum around which samples rotate at a distance of 3.5 cm from the lamps. Solutions of the samples in cyclohexane were irradiated in standard quartz cells, and their concentrations were adjusted so that the same initial maximum absorbance (Abs = 2.0) was maintained. A cyclohexane solution of Tinuvin P (simultaneously irradiated) was used as a reference.[1] All irradiations were carried out at 40 °C. The monitoring of sample photolysis was carried out by recording the full spectra of each solution at different times of irradiation. After the spectrophotometric readings, the samples were again placed in the UV-accelerometer and left to reach the equilibrium temperature (40 °C) before restarting irradiation.

CyH, EtOH, DMSO, and ACN were used as solvents for fluorescence and phosphorescence measurements. Degasification of solutions was performed in a grease-free high-vacuum line by five freeze–degas (10^{-5} Torr)–thaw cycles.

Theoretical Calculations. Proton-transfer curves in the ground state correspond to CNDO/2 calculations[14] on INDO fully optimized geometries of the planar systems, the only limitation being that of keeping the r_{OH} distance fixed during the optimization process. Calculations of electronic excited states, corresponding to the Franck–Condon approximation, have been obtained by using the CNDO/2 method with configuration interaction including the 60 monoexcited configurations of lower energy.

---

[8] Knoll, A.-G. Ger. 931,284, Aug 4, 1955; *Chem. Abstr.* **1958**, *52*, 20201c; Ger. 932,909, Sept 12, 1955; *Chem. Abstr.* **1958**, *52*, 18470e.

[9] Nawrot-Modranka, J.; Kostka, K. *Pol. J. Chem.* **1988**, *62*, 417.

[10] Main, P.; Fiske, S. J.; Hull, S. E.; Lessinger, L.; Germain, G.; Declercq, J. P.; Woolfson, M. M. *Multan 80 System*; University of York: England, 1980.

[11] Steward, J. M.; Machin, P. A.; Dickinson, C. W.; Ammon, H. L.; Heck, H.; Flack, H. The X-ray System. Technical Report TR-446; Computer Science Center: University of Maryland, College Park, MD, 1976.

[12] *International Tables for X-ray Crystallography*; Kynoch Press: Birmingham, England, 1974; Vol. IV.

[13] Catalan, J.; Mena, E.; Fabero, F.; Amat-Guerri, F. *J. Chem. Phys.* **1992**, *96*, 2005.

[14] *Modern Theoretical Chemistry*; Miller, W. H., Schaefer, H. F., Berne, B. J., Segal, G. A., Eds.; Plenum Press: New York, 1977; especially Vol. 7 and 8.

[15] Motherwell, W. D. S. PLUTO: *A Program for Plotting Crystal and Molecular Structures*; Cambridge University: England, 1978.

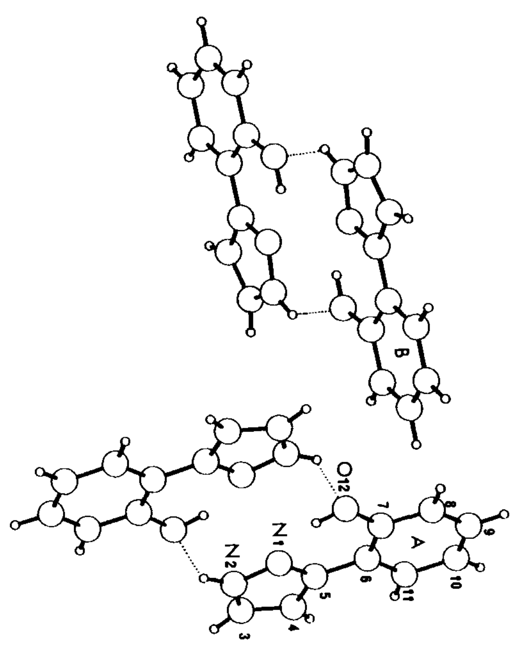


Figure 1. Two independent molecules of compound **5** and the dimers they form; the numbering shown was used in the crystallographic analysis.[10]

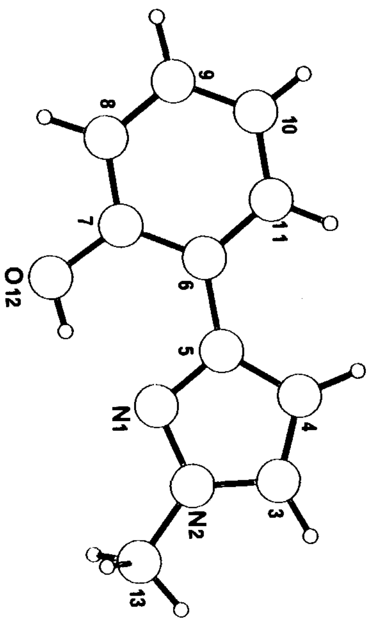


Figure 2. Molecular structure of compound **7** with the atomic numbering.

Results and Discussion

Synthesis. As shown in Scheme I, 3(5)-(2'-hydroxyphenyl)-pyrazoles and their *N*- and *O*-methyl derivatives have been prepared by standard methods.[8,9] Thus, *o*-hydroxyacetophenone (**1**) and *o*-methoxyacetophenone (**2**) reacted with ethyl formate in the presence of powdered sodium to give the corresponding hydroxymethylene intermediates **3** and **4**, which when treated with hydrazine gave 3(5)-(2'-hydroxyphenyl)pyrazole (**5**) and 3(5)-(2'-methoxyphenyl)pyrazole (**6**), respectively.

Reaction of 2-hydroxy-α-(hydroxymethylene)acetophenone (**3**) with methylhydrazine yielded a mixture of 1-methyl-3-(2'-hydroxyphenyl)pyrazole (**7**) and 1-methyl-5-(2'-hydroxyphenyl)pyrazole (**8**), which was conveniently separated into its components by column chromatography. Subsequent methylation of each isomer **7** and **8** with methyl iodide in a basic medium gave finally the dimethyl derivatives **9** and **10**, respectively. The alternative procedure to prepare **9** and **10**, i.e., the reaction of methylhydrazine with β-keto aldehydes **4**, was also attempted but the separation of both isomers proved very difficult (see Experimental Section).

All compounds have been fully characterized by ^{1}H and ^{13}C NMR spectroscopy (see Tables I and II).

X-ray Crystallography (Compounds 5, 7, and 8). The main geometrical characteristics, derived from the crystallographic analysis of compounds **5**, **7**, and **8**, are presented in Table III and the molecular structures are illustrated in Figures 1–3. In the unit cell, compound **5** occurs as two independent "dimeric" molecules (**5A** and **5B**).

The characteristic double bonds of the pyrazole rings appear localized in the *N*-methyl derivatives **7** and **8**. Notice that in compound **7**, the *N*-methyl group is on N (2), thus the 'pyrrolic'; versus 'pyridinic' character of the nitrogen atoms are interchanged due to the different position of the methyl substitution (see Figure

Table I. ^{1}H NMR Data (Chemical Shifts, δ in ppm Relative to Internal TMS, and Coupling Constants, *J* in Hz) in Deuteriochloroform

compound	$H_{3'}$	$H_{4'}$	$H_{5'}$	$H_{6'}$	H_3	H_4	H_5	others
5[a]	7.04 (dd $^3J_{H3',H4'} = 8.2$, $^4J_{H3',H5'} = 1.2$)	7.24 (ddd, $^3J_{H4',H5'} = 7.2$, $^4J_{H4',H6'} = 1.7$)	6.93 (ddd, $^3J_{H5',H6'} = 7.7$)	7.61 (dd)		6.74 (d, $^3J_{H4,H5} = 2.6$)	7.65 (d)	OH, 10.4; NH, 10.4
6[b]	7.04 (d)	7.31 (ddd)	nm[c]	7.69 (dd)	7.61 (d, $^3J_{H3,H4} = 1.9$)	6.65 (d)		OCH_3, 4.00; NH, 12.0
7	7.02 (dd, $^3J_{H3',H4'} = 8.2$, $^4J_{H3',H5'} = 1.3$)	7.20 (ddd, $^3J_{H4',H5'} = 7.2$, $^4J_{H4',H6'} = 1.7$)	6.90 (ddd, $^3J_{H5',H6'} = 7.7$)	7.56 (dd)		6.61 (d, $^3J_{H4,H5} = 2.4$)	7.39 (d)	NCH_3, 3.95; OH, 10.79
8[b]	7.02 (d)	7.34 (ddd)	nm[c]	7.20 (dd)	7.59 (d, $^3J_{H3,H4} = 1.9$)	6.35 (d)		NCH_3, 3.79; OH, 5.89
9	6.97 (d, $^3J_{H3',H4'} = 8.1$)	7.28 (ddd, $^3J_{H4',H5'} = 7.4$, $^4J_{H4',H6'} = 1.8$)	7.01 (ddd, $^3J_{H5',H6'} = 7.6$, $^4J_{H5',H3'} = 1.2$)	7.90 (dd)		6.75 (d, $^3J_{H4,H5} = 2.2$)	7.38 (d)	NCH_3, 3.90; OCH_3, 3.96
10	7.00 (d, $^3J_{H3',H4'} = 8.3$)	7.42 (ddd, $^3J_{H4',H5'} = 7.5$, $^4J_{H4',H6'} = 1.8$)	7.03 (ddd, $^3J_{H5',H6'} = 7.5$, $^4J_{H5',H3'} = 1.0$)	7.26 (dd)	7.53 (d, $^3J_{H3,H4} = 1.9$)	6.25 (d)		NCH_3, 3.73; OCH_3, 3.82

[a] An heteronuclear (^{1}H–^{13}C) 2D-correlation experiment with a *J* value of 166 Hz confirmed the assignment. [b] Due to the overlap of the signals, coupling constants have been measured in DMSO-d_6. Values for compound **6**: $^3J_{H3',H4'} = 8.3$, $^3J_{H4',H5'} = 7.4$, $^3J_{H6',H5'} = 7.6$, $^4J_{H3',H5'} = 1.0$, $^4J_{H4',H6'} = 1.7$. For compound **8**: $^3J_{H3',H4'} = 8.1$, $^3J_{H4',H5'} = 7.4$, $^3J_{H6',H5'} = 7.6$, $^4J_{H3',H5'} = 1.1$, $^4J_{H4',H6'} = 1.7$. [c] nm = not measurable.

Table II. ^{13}C NMR Data (Chemical Shifts, δ in ppm, Relative to Internal TMS and Coupling Constants, J in Hz) in Deuteriochloroform

compound	$C_{1'}$	$C_{2'}$	$C_{3'}$	$C_{4'}$	$C_{5'}$	$C_{6'}$	C_3	C_4	C_5	others
5	116.6 (dd, $^3J(H_{5'}) = 7.9$, $^3J(H_{3'}) = 5.2$)	155.3 (cm)	116.8 (dd, $^1J(H_{3'}) = 159.6$, $^3J(H_{5'}) = 7.7$)	129.2 (dd, $^1J(H_{4'}) = 160.9$, $^3J(H_{6'}) = 8.9$)	119.6 (dd, $^1J(H_{5'}) = 162.2$, $^3J(H_{3'}) = 7.9$)	126.6 (ddd, $^1J(H_{6'}) = 156.7$, $^3J(H_{4'}) = 8.5$, $^2J(H_{5'}) = 2.0$)	151.4 (cm)	101.8 (dd, $^1J(H_4) = 177.3$, $^2J(H_5) = 8.6$)	129.4 (dd, $^1J(H_5) = 184.8$, $^2J(H_4) = 7.8$)	
6	118.0 (t, $^3J(H_{5'}) = 6.4$, $^3J(H_{3'}) = 6.4$)	155.6 (br s)	111.3 (dd, $^1J(H_{3'}) = 159.6$, $^3J(H_{5'}) = 8.1$)	128.9 (dd, $^1J(H_{4'}) = 162.6$, $^3J(H_{6'}) = 9.0$)	121.1 (dd, $^1J(H_{5'}) = 162.5$, $^3J(H_{3'}) = 7.7$)	127.8 (ddd, $^1J(H_{6'}) = 158.5$, $^3J(H_{4'}) = 8.4$, $^2J(H_{5'}) = 1.6$)	138.3 (dd, $^1J(H_3) = 184.5$, $^2J(H_4) = 5.2$)	102.9 (dd, $^1J(H_4) = 175.5$, $^2J(H_3) = 10.8$)	140.9 (d, $^3J(H_3) = 4.5$)	CH_3: 55.5 (q, $^1J = 144.8$)
7	116.7 (dd, $^3J(H_{5'}) = 8.3$, $^3J(H_{3'}) = 5.1$)	155.6 (cm)	116.9 (dd, $^1J(H_{3'}) = 159.8$, $^3J(H_{5'}) = 7.7$)	128.9 (dd, $^1J(H_{4'}) = 160.8$, $^3J(H_{6'}) = 8.7$)	119.2 (dd, $^1J(H_{5'}) = 161.8$, $^3J(H_{3'}) = 7.9$)	126.1 (ddd, $^1J(H_{6'}) = 156.0$, $^3J(H_{4'}) = 8.8$, $^2J(H_{5'}) = 1.9$)	151.3 (dd, $^3J(H_5) = 7.9$, $^2J(H_4) = 5.0$)	102.1 (dd, $^1J(H_4) = 176.8$, $^2J(H_5) = 8.7$)	131.0 (ddd, $^1J(H_5) = 186.4$, $^2J(H_4) = 8.2$, $^3J(H_{CH_3}) = 2.4$)	CH_3: 38.8 (q, $^1J = 140.2$)
8	117.0 (ddd, $^3J(H_{5'}) = 7.2$, $^3J(H_{3'}) = 5.5$, $^2J(H_{6'}) = 1.7$	154.0 (cm)	116.2 (dd, $^1J(H_{3'}) = 160.8$, $^3J(H_{5'}) = 8.3$)	130.9 (dd, $^1J(H_{4'}) = 164.1$, $^3J(H_{6'}) = 8.0$)	119.9 (dd, $^1J(H_{5'}) = 164.0$, $^3J(H_{3'}) = 7.7$)	130.9 (dd, $^1J(H_{6'}) = 158.3$, $^3J(H_{4'}) = 8.6$)	138.7 (dd, $^1J(H_3) = 185.7$, $^2J(H_4) = 5.9$)	106.7 (dd, $^1J(H_4) = 176.5$, $^2J(H_3) = 10.3$)	138.9 (d, $^3J(H_3) = 3.8$, $^3J(H_{CH_3}) = 2.3$)	CH_3: 37.0 (q, $^1J = 140.2$)
9	122.2 (d, $^3J(H_{5'}) = 9.9$)	156.3 (br s)	111.0 (dd, $^1J(H_{3'}) = 159.1$, $^3J(H_{5'}) = 8.1$)	128.3 (d, $^1J(H_{4'}) = 160.5$)	120.4 (dd, $^1J(H_{5'}) = 161.5$, $^3J(H_{3'}) = 7.7$)	128.1 (d, $^1J(H_{6'}) = 157.7$)	147.9 (ddd, $^3J(H_5) = 7.9$, $^2J(H_4) = 4.1$, $^3J(H_{6'}) = 3.6$)	106.6 (dd, $^1J(H_4) = 179.2$, $^2J(H_5) = 8.8$)	130.1 (ddd, $^1J(H_5) = 184.7$, $^2J(H_4) = 9.6$, $^3J(H_{CH_3}) = 2.3$)	OCH_3: 55.0 (q, $^1J = 143.9$) NCH_3: 38.5 (q, $^1J = 139.6$)
10	119.5 (t, $^3J(H_{5'}) = 6.8$, $^3J(H_{3'}) = 6.8$)	156.7 (br s)	110.8 (dd, $^1J(H_{3'}) = 160.3$, $^3J(H_{5'}) = 7.7$)	131.4 (dd, $^1J(H_{4'}) = 160.5$, $^3J(H_{6'}) = 8.7$)	120.4 (dd, $^1J(H_{5'}) = 163.8$, $^3J(H_{3'}) = 7.5$)	130.3 (dd, $^1J(H_{6'}) = 156.5$, $^3J(H_{4'}) = 8.7$)	138.0 (dd, $^1J(H_3) = 184.0$, $^2J(H_4) = 5.7$)	106.5 (dd, $^1J(H_4) = 176.1$, $^2J(H_3) = 10.4$)	140.0 (br s)	OCH_3: 55.2 (q, $^1J = 144.3$) NCH_3: 36.9 (q, $^1J = 139.7$)

Table III. Selected Geometrical Features (Å, deg) of the Molecular Structures of Compounds **5**, **7**, and **8**[15]

	5A	5B	7	8
	a. Bond Distances			
N(1)-N(2)	1.345 (3)	1.351 (3)	1.354 (4)	1.358 (3)
N(2)-C(3)	1.331 (4)	1.345 (3)	1.432 (5)	1.334 (2)
N(1)-C(5)	1.336 (3)	1.339 (3)	1.335 (4)	1.357 (3)
C(3)-C(4)	1.369 (4)	1.368 (4)	1.359 (5)	1.390 (4)
C(4)-C(5)	1.410 (3)	1.410 (3)	1.401 (5)	1.377 (4)
C(5)-C(6)	1.466 (3)	1.469 (4)	1.463 (5)	1.468 (4)
C(7)-O(12)	1.369 (3)	1.366 (3)	1.359 (5)	1.358 (3)
N(1)/N(2)-C(13)			1.451 (6)	1.457 (4)
	b. Bond Angles			
N(2)-N(1)-C(5)	105.8 (2)	105.2 (2)	105.5 (3)	112.0 (2)
N(1)-N(2)-C(3)	111.7 (2)	112.0 (2)	111.4 (3)	104.8 (2)
N(2)-C(3)-C(4)	107.8 (3)	107.2 (2)	107.3 (3)	111.3 (3)
C(3)-C(4)-C(5)	104.8 (2)	105.2 (2)	105.9 (3)	105.8 (2)
C(4)-C(5)-N(1)	109.8 (2)	110.3 (2)	109.9 (3)	106.1 (2)
C(4)-C(5)-C(6)	129.9 (2)	129.8 (2)	130.2 (3)	130.3 (2)
N(1)-C(5)-C(6)	120.6 (2)	119.9 (2)	119.9 (3)	123.6 (2)
C(5)-C(6)-C(7)	121.2 (2)	121.7 (2)	121.5 (3)	121.8 (2)
C(5)-C(6)-C(11)	120.7 (2)	120.4 (2)	120.8 (3)	119.5 (2)
C(7)-C(6)-C(11)	118.1 (2)	117.9 (2)	117.7 (3)	118.6 (2)
C(6)-C(7)-O(12)	122.2 (2)	122.4 (2)	122.7 (3)	117.5 (2)
C(8)-C(7)-C(6)	117.6 (2)	117.2 (2)	117.0 (4)	122.3 (2)
C(7)-O(12)-H(12)	107 (3)	109 (3)	111 (3)	114 (2)
C(5)/C(3)-N(1)/ N(2)-C(13)			128.4 (3)	128.6 (2)
N(2)/N(1)-N(1)/ N(2)-C(13)			120.2 (3)	119.2 (2)
	c. Torsion Angles			
N(1)-C(5)-C(6)-C(7)	-2.7 (4)	0.1 (3)	4.7 (5)	-61.7 (4)
C(5)-C(6)-C(7)-O(12)	-0.7 (4)	0.2 (3)	1.1 (6)	2.8 (4)
C(6)-C(7)-O(12)-H(12)	2 (3)	4 (3)	-2 (3)	-164 (2)

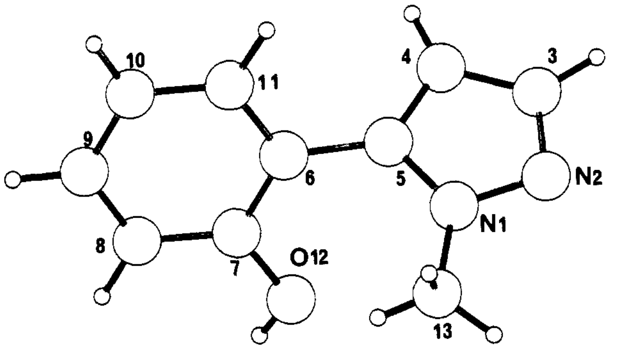


Figure 3. Molecular structure of compound **8** with the atomic numbering.

1-3 and Table III). The same description holds for **5B**, but the structure is more delocalized in **5A**, at least in geometrical terms.

The intracyclic angles at the NH/NMe corners and at the carbon atoms of the N=C bonds of the pyrazole ring possess the typically high values observed for other pyrazole derivatives (cf. ref 1) regardless of the phenyl substitution site. The substitutional angles C-C-Ph and N-C-Ph were typical (cf. ref 1) regardless of the double-bond character. On the other hand, the intramolecular crowding seems to affect the symmetry of the exit angles at the Me and OH substituents, in the C-C-O case the angle on the H-bond site being greater. In the phenyl rings, the bond distances are within the 1.366 (8)-1.410 (3) Å range, with usual shortenings in the extreme ones. Internal bond angles are 120°, except those at the C5 atoms, which are less than 120° [117.7 (3)° for compound **7**].[16]

The torsion angles (see Table III) indicate that in the solid state compounds **5** and **7** are planar and have an intramolecular (O—H···N) hydrogen bond whereas compound **8** is nonplanar (the angle of twist between the two rings is 61.7°).

---

(16) Domenicaco, A.; Vaciago, A.; Coulson, C. A. *Acta Crystallogr.* **1975**, *B31*, 221.

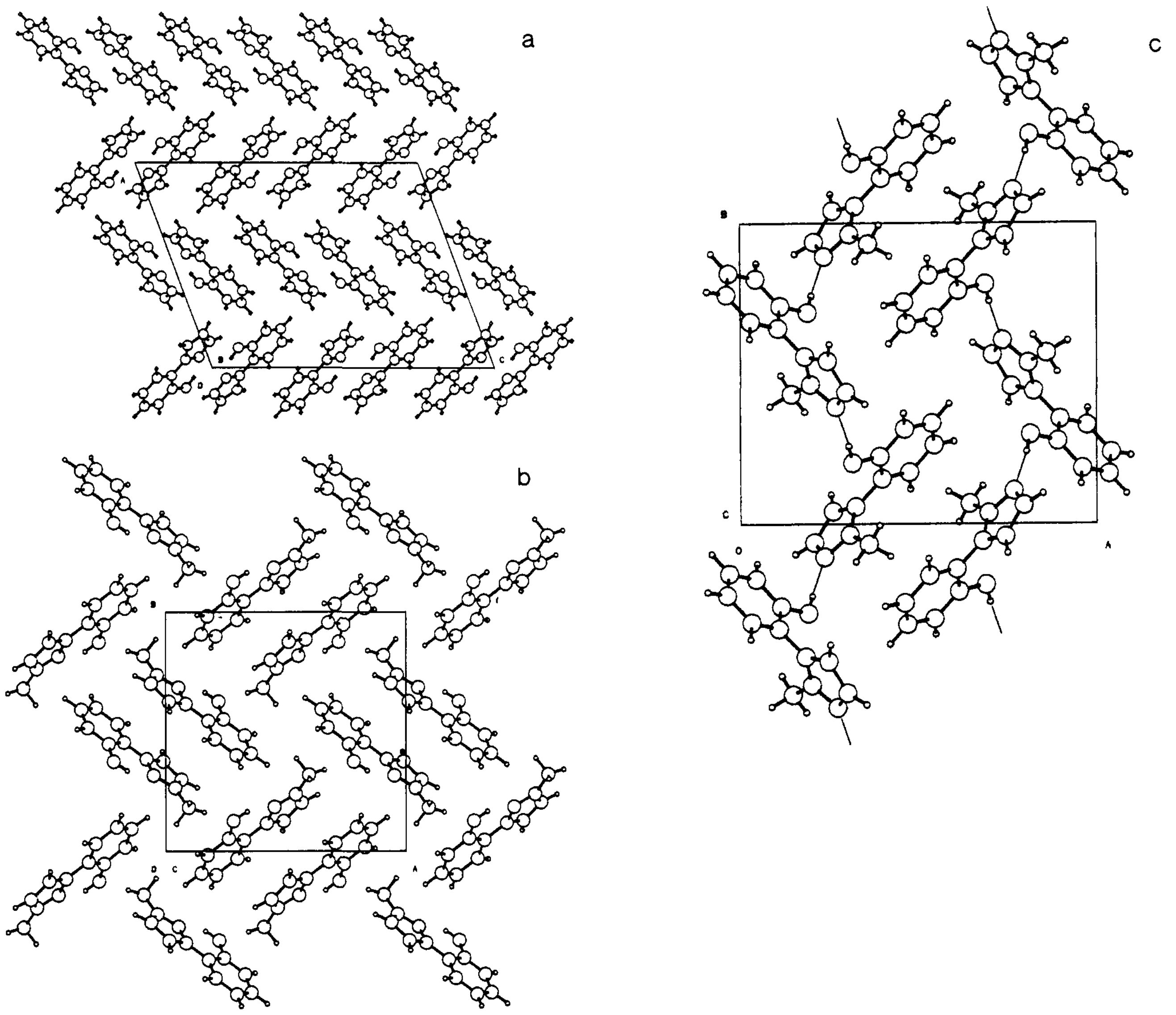


Figure 4. Packing of compounds **5** (a), **7** (b), and **8** (c), as seen in the x,z-plane (compound **5**) and along the screw axis (compounds **7** and **8**). Only the intermolecular H-bond, and no the intramolecular ones, has been drawn for the purposes of clarity.

Table IV. Hydrogen Interactions (Å, deg)[a]

	X	H	Y	X–H	X···Y	H···Y	X—H···Y
5	O(12A)	H(12A)	N(1A)	0.90 (4)	2.595 (3)	1.78 (4)	151 (4)*
	O(12B)	H(12B)	N(1B)	0.89 (5)	2.606 (3)	1.81 (4)	147 (4)*
	N(2A)	H(2A)	O(12A*i*)	0.93 (5)	2.986 (3)	2.22 (5)	138 (3)
	N(2B)	H(2B)	O(12B*ii*)	0.89 (4)	2.859 (3)	2.19 (4)	131 (3)
7	O(12)	H(12)	N(1)	0.87 (5)	2.596 (4)	1.84 (5)	145 (4)*
	C(13*iv*)	H(13C*iv*)	O(12)	0.99 (7)	3.539 (7)	2.59 (7)	161 (5)
	C(3*iv*)	H(3*iv*)	O(12)	1.00 (4)	3.465 (7)	2.55 (4)	152 (4)
8	O(12)	H(12)	N(2*iii*)	0.84 (3)	2.715 (3)	1.88 (3)	173 (3)*
	C(13)	H(13A)	O(12)	0.90 (4)	3.109 (4)	2.55 (5)	121 (4)
	C(13*iii*)	H(13B*iii*)	O(12)	0.98 (4)	3.457 (4)	2.71 (4)	133 (3)

[a] Those marked with an asterisk are to be considered hydrogen bonds.[18] Italics stand for symmetry codes: $i = -x, 1 - y, -z$; $ii = 1 - x, 1 - y, -z$; $iii = {}^1/_2 - x, {}^1/_2 + y, 2 - z$; $iv = x - {}^1/_2, {}^1/_2 - y, {}^1/_2 + z$.

The crystal structure of **5** resembles, in the x,z-projection, a "herringbone"-like packing along c[17] (see Figure 4a), although the stacking is up and down one-half of the b axis. The two sequences of inclined "bones" are crystallographically independent and, within each, the molecules are associated in a sort of dimeric structure that possesses a center of symmetry. Within each molecule, there is an intramolecular bond (see Table IV), with quite asymmetric angles at the acceptor: H···N1—Z = 155 (4)° vs 99 (4)° and 155 (3)° vs 100 (4)° for molecules A and B, respectively.

Compound **8** presents a 2-fold helical packing in chains along the b axis, through an intermolecular hydrogen bond (see Table IV, where some other possible interactions are shown), with angles at the acceptor of 137 (4)° and 118 (3)°. These chains are related by symmetry centers, in such a way that the structure appears like a distorted "sandwich herringbone" packing with some tetragonal-like aspect around c (see Figure 4c and axis ratio).

The tetragonal tendency just mentioned becomes more apparent

---

(17) Desiraju, G. R.; Gavezzotti, A. *Acta Crystallogr.* **1989**, *B45*, 473–482.

(18) Vainshtein, B. K.; Fridkin, V. M.; Indenbom, V. L. *Modern Crystallography II*; Springer: New York, 1982; p 87.

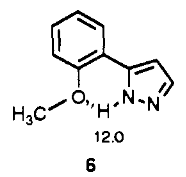
in the structure of compound **7** (see Figure 4b). There is also present the "sandwich herringbone" packing along the *b* axis, an axis that holds the helicity, present here as well. The molecular network is set here by a system of hydrogen interactions (see Table IV). There is also, like in compound **5**, an intramolecular bond, the angles at the acceptor being 154 (5)° vs 100 (4)°.

NMR Spectroscopy. In Tables I and II are assembled the ^1H and ^{13}C NMR spectroscopic data for compounds **5–10**. The ^{13}C NMR signals of the carbon atoms in the pyrazole rings were assigned by comparison with those of the corresponding carbons of 3-phenylpyrazole, 1-methyl-3-phenylpyrazole, and 1-methyl-5-phenylpyrazole (cf. ref 19). The ^1H and ^{13}C coupling constant criteria previously applied (cf. ref 20) to the assignment of 1,3- and 1,5-disubstituted pyrazoles were also found to be of value. These criteria are the following: (^1H NMR) $^3J(H_3H_4) < {}^3J(H_4H_5)$; ($^{13}C$ NMR) $^2J(C_3H_4) < {}^2J(C_5H_4)$; $^3J(C_3H_5) > {}^3J(C_5H_3)$; $^2J(C_4H_5) < {}^2J(C_4H_3)$.

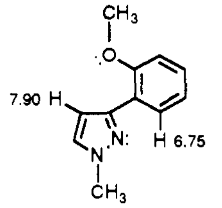
For the assignment of protons and carbons of the phenyl group, the known influence of hydroxy and methoxy substituents (cf. ref 21) was also taken into account, together with the multiplicity of the signals and coupling constant values.

In those pyrazoles, e.g., **5** and **6**, where a prototropy is involved, the ^3J coupling constants between pyrazole protons in various solvents (see supplementary material) were compared with those of compounds **7–10** where prototropy cannot occur. From the experimental data, we conclude that the parent pyrazole **5** exists in all solvents in the 1H-3-(2′-hydroxyphenyl) form, whereas compound **6** appears to be predominantly a 1-H-5-(2′-methoxyphenyl)pyrazole.

The ^{13}C NMR chemical shifts of the heterocyclic carbons in derivatives **5**, **7**, and **9** have almost the same values ($\delta C_3 \sim 150.2$; $\delta C_5 \sim 130.2$), a finding which supports the assignment of the 1H-3-arylpyrazole structure to phenol **5**. A similarly close relationship was found for the chemical shifts ($C_3 \sim 138.3$; $C_5 \sim 139.9$) of compounds **6**, **8**, and **10**, and therefore ether **6** must have the 1H-5-arylpyrazole structure. Indeed X-ray crystallography had already shown that the phenol **5** has the 3-arylpyrazole structure in the solid state. In general, 3-aryl tautomers are preferred to 5-aryl tautomers. The preference for the 5-aryl structure in the case of ether **6** is probably related to the formation to an IMHB between the NH and the ether oxygen (see structure **6**).



6



9

In Tables I and II there can be found further information regarding the conformation of compounds **5–10**. The most useful information in this regard is the proton chemical shift values[22] (see Table I) of the ortho protons, $H_{6'}$ (aryl ring) and H_4 (pyrazole ring), and of the pyrazole proton (H_4) and the ^{13}C chemical shift difference ($\Delta\delta = \delta C_{6'} - \delta C_{5'}$) between the ortho and the meta carbons[23] (see Table II). The planar compounds, **5**, **6**, **7**, and **9**, have the following averaged values: $\delta H_{6'} = 7.7$, $\delta H_4 = 6.7$, and $\Delta\delta = 7.0$ ppm, whereas the nonplanar compounds, **8** and **10**, have $\delta H_{6'} = 7.2$, $\delta H_4 = 6.3$, and $\Delta\delta = 10.4$ ppm. Since the X-ray structures of both ethers **6** and **9** have not been determined, the above-described application of NMR spectroscopy was particularly important for the assignment of structure to these two compounds. We conclude that both compounds are almost planar [diagnostic ^1H NMR data are appended to their formulas (see above)]. In the case of ether **6**, the highly deshielded NH signal indicates the existence of an IMHB. Ether **9** probably exists in the *E*-conformation shown.

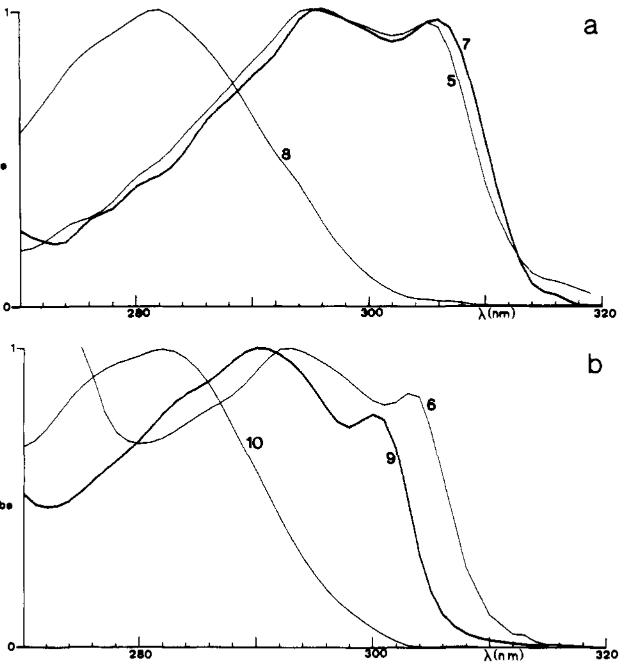


Figure 5. First UV absorption band in dry CyH of (a) 1-H-3-(2′-hydroxyphenyl)pyrazole (**5**), 1-methyl-3-(2′-hydroxyphenyl)pyrazole (**7**), and 1-methyl-5-(2′-hydroxyphenyl)pyrazole (**8**); (b) 3(5)-(2′-methoxyphenyl)pyrazole (**6**), 1-methyl-3-(2′-methoxyphenyl)pyrazole (**9**), and 1-methyl-5-(2′-methoxyphenyl)pyrazole (**10**).

Photophysical Studies. The ultraviolet spectra of all compounds were recorded in cyclohexane, ethanol, acetonitrile, and dimethyl sulfoxide solution, and it was found that the UV absorption maxima were practically independent of the nature of the solvent. For the following discussion it is important to know that is has been established,[24] both experimentally and theoretically, that the absorption spectra of 3(5)-phenylpyrazole is relatively insensitive to tautomerism but very dependent on the dihedral angle between the pyrazole and the phenyl rings. In addition these spectra (Figure 5) provided further evidence (see above) that compounds **5–7** and **9** are planar or nearly so in these particular solvents and that compounds **8** and **10** are nonplanar [in the solid state, phenol **8** possesses a torsion angle of 61.7° (see Table III)]. Furthermore, the fact that the spectra of phenols **5** and **7** are almost identical with one another (Figure 5a) constitutes additional proof that they are both 3-arylpyrazoles.

The spectra of the methoxy derivatives **6** and **8** (Figure 5b) are similar but not identical with one another; this observation presumably reflects the finding (cf. NMR discussion above) that compounds **6** and **9** are 5-aryl- and 3-arylpyrazole derivatives, respectively.

Pyrazoles **5** and **7** exhibit a first absorption band at 306 nm, a feature which denotes that in the ground state there is an intramolecular hydrogen bond; hence the pyrazole and phenyl rings lie in the same plane, and conjugation therefore occurs. Compounds **6** and **9** also exhibit a first absorption band in the 300-nm region; i.e., the two rings are conjugated with one another. In the 1,5-disubstituted pyrazoles the absorption is shifted to the blue, appearing at 282 nm probably due to the existence of these ste-

---

(19) Cabildo, P.; Claramunt, R. M.; Elguero, J. *Org. Magn. Reson.* **1984**, *22*, 603.

(20) López, C.; Claramunt, R. M.; Sanz, D.; Foces-Foces, C.; Cano, F. H.; Faure, R.; Cayon, E.; Elguero, J. *Inorg. Chim. Acta* **1990**, *176*, 195.

(21) Pretsch, E.; Clerc, T.; Seibl, J.; Simon, W. In *Tabellen zur Strukturaufklärung Organischer Verbindunger mit Spektroskopischen Metoden*; Springer: Berlin, 1976.

(22) Elguero, J.; Jacquier, R.; Tarrago, G. *Bull. Soc. Chim. Fr.* **1970**, 1345. Tarrago, G.; Ramdani, A.; Elguero, J.; Espada, M. *J. Heterocycl. Chem.* **1980**, *17*, 137.

(23) Avignon, T.; Bouscasse, L.; Elguero, J. *Tetrahedron* **1978**, *34*, 1139; Begtrup, M.; Elguero, J.; Faure, R.; Camps, P.; Estopa, C.; Ilavsky, D.; Fruchier, A.; Marzin, C.; de Mendoza, J. *Magn. Reson. Chem.* **1988**, *26*, 134.

(24) Cativiela, C.; Laureiro, J. I. G.; Elguero, J.; Elguero, E. *Gazz. Chim. Ital.* **1991**, *121*, 477.

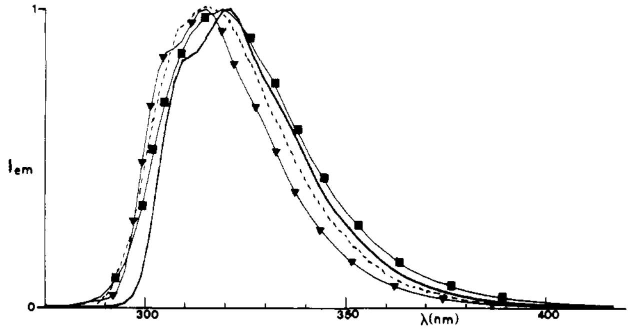


Figure 6. Fluorescence spectra in dry CyH of compounds **6** (—), **8** (- - -), **9** (▼), and **10** (■).

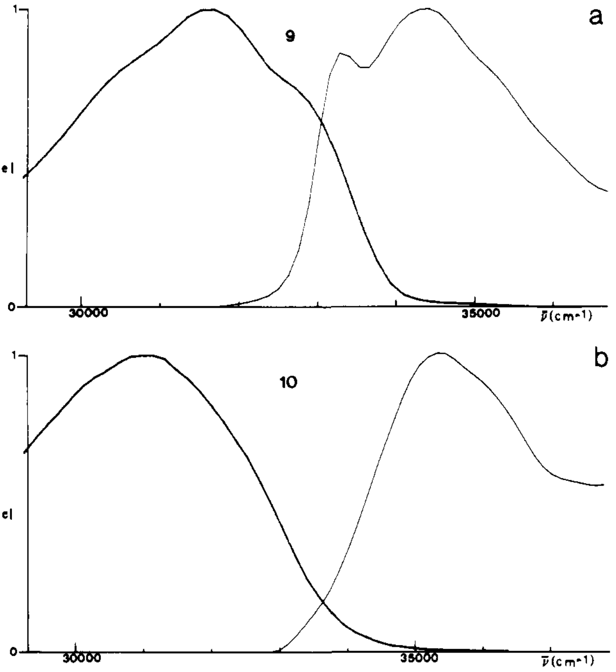


Figure 7. Modified absorption spectra, $\epsilon(\nu/\nu)$ (—), and modified fluorescence spectra, $F(\nu/\nu^3)$ (—), vs ν in 1-methyl-3-(2′-methoxyphenyl)pyrazole (**9**) and 1-methyl-5-(2′-methoxyphenyl)pyrazole (**10**).

rically hindered derivatives in nonplanar forms.

The emission spectra of 3(5)-(2′-methoxyphenyl)pyrazole (**6**), 1-methyl-5-(2′-hydroxyphenyl)pyrazole (**8**), 1-methyl-3-(2′-methoxyphenyl)pyrazole (**9**), and 1-methyl-5-(2′-methoxyphenyl)pyrazole (**10**) indicated that these compounds were fluorescent in dry and degasified cyclohexane at room temperature with maxima around 320 nm (see Figure 6), whereas the 1-R-3-(2′-hydroxyphenyl)pyrazoles **5** (R = H) and **7** (R = Me) did not fluoresce at all in this UV region (see also the Proton Transfer section). These observations suggest that compounds **6** and **8–10** emit from a common structural unit.

In 1-methyl-3-(2′-methoxyphenyl)pyrazole (**9**) specular symmetry[25] was evidenced but not in 1-methyl-5-(2′-methoxyphenyl)pyrazole (**10**) (see Figure 7); i.e., for compound **9**, emission occurs from a molecular structure similar to that present in the electronic ground state. However, for compound **10** the molecular structure in the first singlet electronic excited state is sensibly different from that present in the ground state. Besides, it is a well-known fact[13] that some 2-phenylbenzazoles that are nonplanar in the ground state have a great tendency to become planar in the excited state as the result of a major resonance effect between the aromatic rings.

When a small amount of EtOH was added to the foregoing solutions, the fluorescence of **6** and **8–10** was enhanced, compound **5** emitted very weakly, and **7** remained not fluorescent in the UV region.

Table V. Fluorescence Quantum Yields of Derivatives **5–10** at a λ^{ex} (nm) = 320

compound	CyH[a]	ACN[b]	DMSO[b]	EtOH[b]
5	not detected	0.013	0.135	0.098
6	0.735	0.422	0.545	0.671
7	not detected	0.004	0.085	0.041
8	0.057	0.261	0.265	0.381
9	0.932	0.401	0.532	0.607
10	0.443	0.319	0.446	0.395

[a] Referred to 1-methyl-2-phenylbenzimidazole in CyH (ϕ_F = 0.70).[13] [b] Referred to 1,4-dihydroxy-2,5-bis(pyrazol-1′-yl)benzene (**11**) in DMSO (ϕ_F = 0.327).[1]

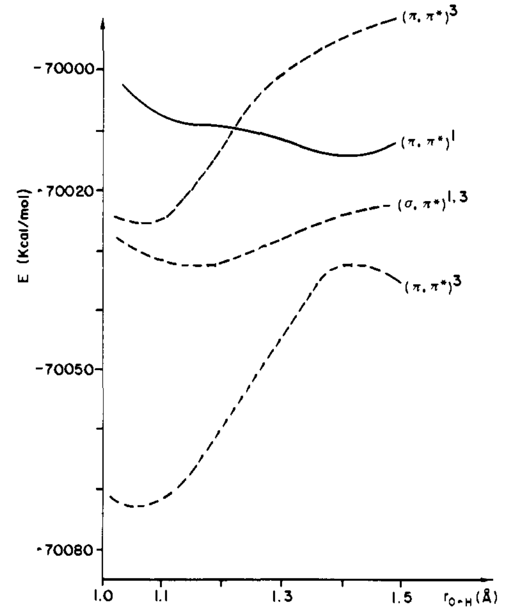


Figure 8. Single-proton-transfer Franck–Condon curves for several excited electronic states of 1-H-3-(2′-hydroxyphenyl)pyrazole (**5**).

In DMSO, EtOH, and ACN, air-equilibrated solutions of derivatives **5–10** fluoresce with emission maxima at 320 nm, the fluorescence exhibited by the 1-R-3-(2′-hydroxyphenyl)pyrazoles **5** and **7** being weaker than that of the other derivatives. This fact could imply that the IMHB of such compounds had been weakened or even broken, but the present situation is quite different from what took place in Tinuvin P in which the emitting form was excited at the wavelength corresponding to the second absorption maxima, so shifted to the blue zone in the UV spectra.

In summary, in all solvents the 3-substituted derivatives have an absorption maxima at 306 nm and the 5-substituted ones at 282 nm. Both emit in polar solvents at 320 nm, suggesting a common structure in the first excited state, which is presumably planar. Examination of fluorescence quantum yield values (see Table V) suggest that 1-methyl-5-(2′-methoxyphenyl)pyrazole (**10**) might be a good candidate as a laser dye in the UV zone.

Proton Transfer. In Figure 8 we present the Franck–Condon curves corresponding to the proton transfer of 1-H-3-(2′-hydroxyphenyl)pyrazole (**5**) (IIa* → IIb*); it appears that, in the first excited singlet state, the proton transfer is energetically possible and should occur. As far as CNDO calculations are reliable, the situation for the first excited triplet appears markedly diffeent: according to the potential energy diagram, the proton transfer would not take place and the energy minimum would correspond to the nontransferred form.

In order to provide evidence for intramolecular proton transfer (IMPT) in 1-H-3-(2′-hydroxyphenyl)pyrazole (**5**) and 1-methyl-3-(2′-hydroxyphenyl)pyrazole (**7**), we prepared a 10^{-4} M solution in dry CyH and used a perpendicular assembly with excitation and emission optical paths of about 1 mm. The fluorescences obtained with the very large Stokes shift of 16 000

---

(25) (a) Birks, J. B.; Dyson, D. J. *Proc. R. Soc. London* **1963**, *A275*, 135. (b) Birks, J. B. *Photophysics of Aromatic Molecules*; Wiley-Interscience: London, 1970; p 85.

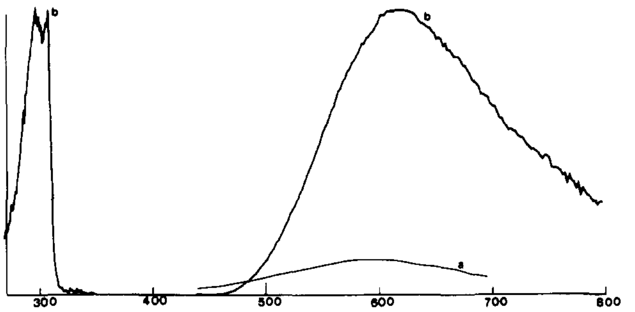


Figure 9. (a) Fluorescence spectra of 1-H-3-(2′-hydroxyphenyl)pyrazole (**5**) in dry CyH (10^{-4} M). (b) Fluorescence and excitation spectra of 1-methyl-3-(2′-hydroxyphenyl)pyrazole (**7**) in dry CyH (10^{-4} M).

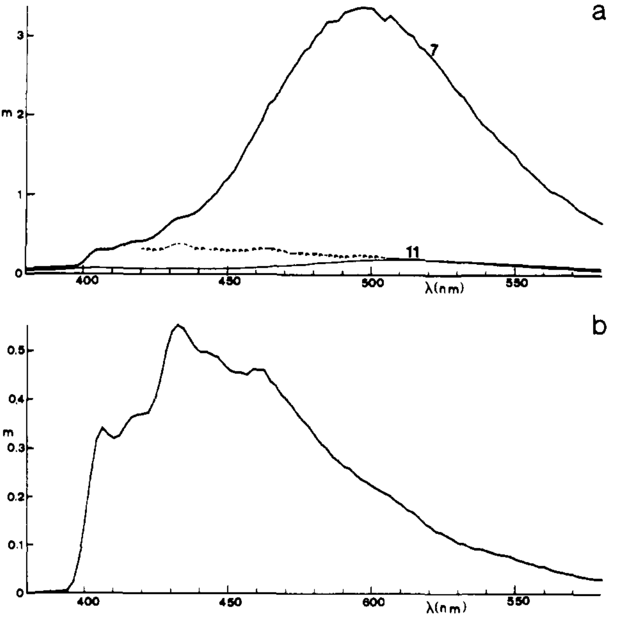
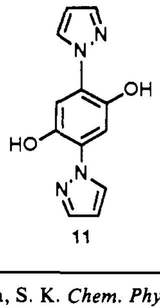


Figure 10. Emission spectra: (a) in dry CyH at 77 K of 1-methyl-3-(2′-hydroxyphenyl)pyrazole (**7**) (—) and 1,4-dihydroxy-2,5-bis(pyrazol-1′-yl)benzene (**11**) (—), in methylcyclohexane/2-methyl butane (1:1) of compound **11** (---); (b) of compound **7** in dry CyH at 77 K with a delay of 3 ms.

cm^{-1} are shown in Figure 9. We account for the difference between this value and the corresponding value of 9257 cm^{-1} reported for 2-(2′-hydroxyphenyl)benzimidazole in CyH[26] as being due to the lower intrinsic basicity of the pyrazole derivative.[27] Consequently, the phenolic OH proton transfer to pyrazole will be more repulsive in the ground state and the emission of the protonic transfer form will shift to lower energy. The excitation and absorption spectra of compound **7** exactly coincide (see Figures 5a and 9). The methyl ether **9** does not emit in the range 420–700 nm.

To clarify the IMPT mechanism, we studied in dry CyH at 77 K 1-methyl-3-(2′-hydroxyphenyl)pyrazole (**7**) comparatively with 1,4-dihydroxy-2,5-bis(pyrazol-1′-yl)benzene (**11**), which had been thoroughly investigated by us in a previous paper.[1]



11

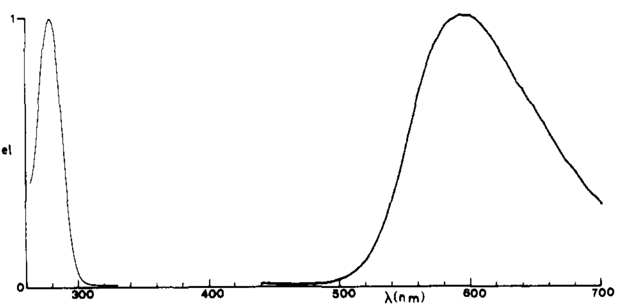


Figure 11. Fluorescence and excitation spectra of 1-methyl-5-(2′-hydroxyphenyl)pyrazole (**8**) in dry CyH.

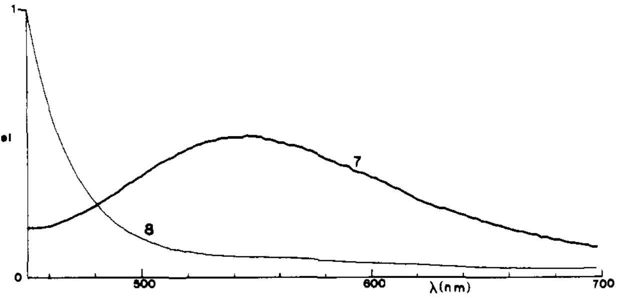


Figure 12. Emission spectra in DMSO of 1-methyl-3-(2′-hydroxyphenyl)pyrazole (**7**) and 1-methyl-5-(2′-hydroxyphenyl)pyrazole (**8**).

As seen in Figure 10a, compound **7** gives emission in the range of 400–600 nm, showing some weak signals at the origin of this emission. In Figure 10b is presented the spectrum of **7** obtained with a delay of 3 ms. These experiences prove that the weak signals correspond to the phosphorescence. In consequence the triplet will be of higher energy than the singlet responsible for fluorescence. Because the excitation spectra of this emission corresponds to the absorption of **7**, there is no doubt that the detected triplet corresponds to the nontransferred form. Attention must be paid to the fact that **11** does not emit either in dry CyH or in methylcyclohexane/2-methylbutane (1:1) (see Figure 10a).

1-Methyl-5-(2′-hydroxyphenyl)pyrazole (**8**), which does not possess an IMHB and absorbs at 282 nm, shows at room temperature an emission maxima at 590 nm (Figure 11). The double **intermolecular** proton transfer (IIIa* → IIIb*) in a structure of the same nature as the one detected by X-ray in the crystal of **8** would account for that emission, also considering that in 1-methyl-5-(2′-methoxyphenyl)pyrazole (**10**) there is no emission at this wavelength.

The latter hypothesis is supported by the fact that a solution of phenol **8** in a basic solvent, e.g., DMSO does not emit due to its existence in solvated monomeric forms (Pz–Ph–OH···DMSO) which are unable to transfer protons in the intermolecular manner. The emission of 1-methyl-3-(2′-hydroxyphenyl)pyrazole (**7**) with an intramolecular hydrogen bond is maintained in DMSO (Figure 12).

Photostability Studies. We carried out a comparative study of the photostability of the six derivatives **5**–**10** and of Tinuvin P in cyclohexane solutions at 40 ± 1 °C with the UV-accelerometer system. To normalize the absorbance values we calculated for each compound (including Tinuvin P) the absorption correction factor from the overlapping area between the different spectra and the spectral distribution curve of the lamp radiation. From the slope of the linear relationship of absorbances (Abs_t/Abs_0) in CyH against irradiation time, a quantitative estimation of their photostabilities was obtained (see supplementary material).

Phenols **5** and **7** and Tinuvin P showed remarkable photostability, their UV characteristics remaining unaltered during 2 h of irradiation. 1-Methyl-3-(2′-hydroxyphenyl)pyrazole (**7**) proved to be more stable than Tinuvin P. After 9 h of irradiation, the percentage of photodestruction was found to be 8.5, 23.5, and 35% for phenol **7**, Tinuvin P, and phenol **5**, respectively. The order of decreasing photostability (see Table VI) for all the compounds

---

(26) Sinha, H. K.; Dogra, S. K. *Chem. Phys.* **1986**, *102*, 337.

(27) Catalán, J.; Abboud, J. L. M.; Elguero, J. *Adv. Heterocycl. Chem.* **1987**, *41*, 187.

Table VI. Photostabilities

compound	irradiatn time to get a 50% reduction of the initial compd concn, h/min	photodegradation velocity,[a] (mol L^{-1} h^{-1}) × 10^6
5	11/43	1.62
Tinuvin P	17/02	
7	47/05	0.46
6	3/55	4.29[b]
8	3/40	8.98[b]
9	4/10	5.18
10	2/56	11.75

[a] Expressed in molarity diminution with irradiation time. Calculated from the slope of the relationship of absorbance versus irradiation time and conversion to concentration units. [b] The inversion of the photodegradability order is due to the difference between the molar absorption coefficients of both compounds.

studied in this investigation was found to be as follows: phenol **7** > Tinuvin P > phenol **5** >>> ether **9** > ether **6** ≥ phenol **8** > ether **10**. This order is clearly related to the possibility of forming an intramolecular O—H···N hydrogen bond (IMHB).

Conclusions

1-H-3-(2′-hydroxyphenyl)pyrazole (**5**) and 1-methyl-3-(2′-hydroxyphenyl)pyrazole (**7**), which each possess an IMHB linking their phenol proton with the pyrazole N2 lone pair, are photostable. In the first excited singlet state, significant conjugation exists between the two rings of the molecule and therefore rotation about the central carbon–carbon bond is restricted.

These derivatives show proton transfer in the first excited singlet; i.e., their behavior in this regard is different from that of *N*-(2′-hydroxyphenyl)pyrazoles. The existence of an IMHB provides UV stability independently of whether the proton is transferred or not.

Experimental evidence proves that the phosphorescence of compounds **5** and **7** is produced by the nontransferred form. Proton transfer does not occur in the triplet state.

Finally, 1-methyl-5-(2′-methoxyphenyl)pyrazole (**10**) is nonplanar in the ground state but becomes planar in the excited state. The fluorescence emission occurs in the range of 300–340 nm with a good quantum yield. The photophysical properties of this compound suggest that it might behave as an excellent laser dye in the ultraviolet region.

Acknowledgment. We are greatly indebted to CICYT of Spain for financial support (project PB87-0094-C02). Two of us (M.D.S.M. and F.F.) thank the Ministry of Education (MEC) and the Comunidad de Madrid of Spain for two FPI grants. Tinuvin P has been kindly supplied by Ciba-Geigy. Fruitful discussions with Dr. J. F. K. Wilshire have been of the utmost importance in preparing this manuscript.

Registry No. **1**, 118-93-4; **2**, 579-74-8; **3**, 87059-79-8; **4**, 140226-33-1; **5**, 34810-67-8; **6**, 59843-63-9; **7**, 123532-18-3; **8**, 123532-22-9; **9**, 140226-34-2; **10**, 140226-35-3.

Supplementary Material Available: Table of ^1H NMR ^3J (between pyrazole protons) coupling constant values in different solvents, tables of final atomic coordinates, anisotropic thermal factors, and hydrogen parameters for compounds **5**, **7**, and **8**, Figure A of the first UV absorption band of compounds **5–10** in CyH, EtOH, ACN, and DMSO, and Figure B showing the changes in absorbance as a function of ultraviolet exposure for CyH solutions of Tinuvin P and derivatives **5–10**, during the initial 8 h of irradiation (14 pages); listing of observed and calculated structure amplitudes (24 pages). Ordering information is given on any current masthead page.

Intermolecular π Electron Interactions Made Visible. Correlation of Ground- and Excited-State Interactions with Specific Photoreactivities of Isomorphously Crystallized Isoelectronic Compounds[1]

Ingo Ortmann,[†] Stefan Werner,[‡] Carl Krüger,*,[‡] Siegfried Mohr,[§] and Kurt Schaffner*,[†]

Contribution from the Max-Planck-Institute für Kohlenforschung und Strahlenchemie, D-4330 Mülheim a. d. Ruhr, Germany. *Received November 18, 1991*

Abstract: Solid-state UV irradiation of crystalline 4-acetoxy-6-styryl-α-pyrone **1b** yields [2π + 2π] dimers of different constitutions (**2b**, 26%; **3b**, 30%) at 69% conversion of **1b**. This dichotomy is a consequence of the crystal topology of **1b**, which contains two topochemically relevant reaction centers, each composed of two monomers arranged at a center of inversion. In contrast, the isomorphously crystallized isoelectronic 4-acetoxy-6-styryl-1,5-oxazinone **4** is photostable. The electronic properties of **1b** and **4** in the ground and excited states correlate with this difference in photoreactivity. Pyrone **1b** exhibits monomer and excimer fluorescence emission in dilute solution and in the crystal, respectively, whereas the oxazinone **4** under both conditions shows solely monomer fluorescence. Furthermore, the electron deformation density (EDD) of **1b**, determined by the X-X method (the resolution is such that the lone pairs at all heteroatoms of **4** and the localization of the styryl C═C double bond are distinctly visible), shows that the main axes of the nonspheric elongation of positive EDD contour lines are turned from right angles to the molecular plane in order to avoid repulsive π–π interactions. This indicates intermolecular π–π electron interaction between the two reacting double bonds of neighboring molecules of **1b**. The corresponding contour lines of the photostable oxazinone **4** do not show any such distortion. Multipole expansions of the atoms in the crystal structure analyses are in agreement with the results obtained from standard structural refinement.

Solid-state [2π + 2π] photocycloaddition of the naturally occurring 5,6-dehydrokawain (the 4-methoxy-6-styryl-α-pyrone, **1a**) has been reported to yield the unsymmetric dimer **2a**, which has also been isolated from the higher fungi *Aniba gardneri* and

---

[†] Strahlenchemie.

[‡] Kohlenforschung.

[§] Institut für Organische Chemie, Universität Kiel, D-2300 Kiel, Germany.

(1) Taken in part from Ortmann, I. Ph.D. Thesis, Max-Planck-Institute für Kohlenforschung und Strahlenchemie, Mülheim a. d. Ruhr, and Bergische Universität, Wuppertal, Germany 1991.

0002-7863/92/1514-5048$03.00/0 © 1992 American Chemical Society