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Synthesis and physico-chemical properties of a novel series of aromatic electron acceptors based on *N*-heterocycles

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ABSTRACT

The synthesis of a novel series of N-based heterocyclic salts using a simple and efficient N-alkylation of 1,2-bis(4-pyridyl)ethane with reactive halides is reported. These compounds can be transformed into the corresponding pyridinium methylides by addition of a base. The former exhibit an unstable absorption bands at 395-410 nm. The structures of the salts were fully characterized by UV-vis, IR, NMR and MS spectroscopy and elemental analysis. The pK values of selected compounds were also determined and the acid-basic equilibrium was investigated by UV-vis spectrophotometry. The thermal stability of all species was determined by thermogravimetric analysis.

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1. Introduction

Pyridinium quaternary salts are a versatile class of compounds having a wide range of interesting properties and continuing to receive an increasing attention.¹⁻¹⁰ This is mainly because they can be easily functionalized at the nitrogen heterocyclic atom in order to obtain useful species for biological and industrial applications,^{1–16} for example, cosmetics, pharmaceuticals, gene delivery and polymerization.^{4,5} Moreover, pyridinium salts attract the attention of scientists because they can be employed as electron carriers, model systems in photosynthesis, cardiovascular agents, hypotensive, neuromuscular agents,^{6,7} and they are also effective as phase transfer agents and catalyst, initiators of cationic polymerization, acylating agents,^{8,9} wide range antimicrobials,^{1,2,10,16} enzyme inhibitors,¹¹ dyes,¹² and cationic surfactants.¹⁴ Selected salts were also found to be ionic liquids¹⁵ whereas others named viologens (4,4'-bipyridinium salts) demonstrate electrochromic properties.¹⁷

Pyridinium salts can also be transformed in their corresponding pyridinium ylides, nucleophilic 'zwitterionic' structures, by addition of a base. This property is important for the synthesis of new heterocyclic compounds by dipolar cycloaddition (Scheme 1).¹⁸

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The ylides are coloured compounds, which in acidic condition became colourless due to their transformation into the corresponding salts.¹⁹



Scheme 1. Ylide formation in basic conditions.

Following our interest in the synthesis of N-base quaternary salts that can be used as precursors for obtaining, through cycloaddition reactions, fluorescent or antimicrobial indolizine compounds, 20-23 we describe here the synthesis and characterization of a new series of quaternary pyridinium salts, based on 1,2-bis(4-pyridyl)ethane, a molecule containing three distinct parts: a flexible unit, a rigid polarisable aromatic core, and a positively charged pyridinium ring associated to a negatively charged counterion. In order to apply these species in the fields above described we have also decided to measure their dissociation constants (*pK*a) that gives information on the chemical reactivity, salt



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formation and chromatographic separation, and to study the thermal stability by TGA that informs about the temperature range where the investigated compounds may be used and stored.

2. Results and discussions

2.1. Synthesis

The synthesis of the quaternary pyridinium salts **1–11** (Scheme 2) derived from 1,2-bis(4-pyridyl)ethane has been carried through the alkylation of 1,2-bis(4-pyridyl)ethane by reactive halogenated derivatives in anhydrous solvents, which seems to be the most convenient method between those reported in literature.^{4,11–13} The structure of **1–11** has been assigned on the basis of IR, ¹H NMR and ¹³C NMR spectroscopy, MS and elemental analysis, while its purity was confirmed by HPLC.



6: R1=H, R2=OCH3, R3=H, R4=H, R5=H, X=Br 7: R1=OH, R2=OH, R4 =H, R5=H, X=Cl 8: R1=H, R2=H, R3=OH, R4=Br, R5=CH3, X=Br

10: R=-CH₂-COOCH₂CH₃, X=Br 11: R=-CH2-CH2-NO2, X=Br

Scheme 2. Synthesis of diquaternary salts of bis(pyridinium).

The IR spectra of the pyridinium salts **1–11** show characteristic bands in the following range: $3040-3000 \text{ cm}^{-1}$ ($\nu \text{CH}_{\text{arom}}$), 2900–2880 cm⁻¹ (ν CH_{aliph}), 1730–1722 cm⁻¹ (ν C=O_{ester}), 1700–1670 cm⁻¹ (vC=0), 1640–1630 cm⁻¹ (vC=N), 1530 and 1350 cm⁻¹ (ν NO₂), 1200 and 1100 cm⁻¹ (ν C–O–C) and ~990 cm⁻¹ (C-C_{aliph}). The molecular structures of 1-11 were further confirmed by ¹H NMR spectroscopic analysis. All these compounds show multiple peaks in the region of 9.10-7.20 ppm, which can be assigned to aromatic protons. Additionally, the characteristic peaks at 6.66–5.67 ppm can be attributed to the CH₂ or CH close to the cationic nitrogen whereas the peak centred at 3.39-3.54 ppm is due to the bridging CH₂. Also, it is evident that the protons from the pyridinium rings are shifted to the low field when compared with 1,2-bis(4-pyridyl) ethane (Table 1). The ¹³C NMR spectra also confirm the synthesised structures. Thus, for compounds 1-8 at 188-195 ppm appear the signals of the quaternary carbon of carbonyl groups, while the signals of the ester carbonyl groups for compounds 9, 10 appear at 166 ppm. At high fields (~56-73 ppm) we found the signals for CH₂ or CH groups close to the pyridinium nitrogen, whereas the signals from 33 to 35 ppm can be attributed to carbons of the bridging CH₂ groups.

Due to the ionic structure of the synthesized compounds, their electrospray mass spectra (ESI-MS) have a major peak for the signal of organic ions $[M^{2+}-H^+]$, with masses between 329 and 639, where M^{2+} represents the mass of the organic skeleton from the diquaternary salt molecules.

2.2. Determination of acid dissociation constants of diquaternary salts

As mentioned above, we are interested in the use of the 1,2bis(4-pyridyl)ethane diquaternary salts as synthons in cycloaddition reactions to obtain fluorescent indolizines (Scheme 3). Important information concerning the salts tendency to form the

Table 1	
Selected ¹ H NMR data of compound 1-11 and	1,2-bis(4-pyridyl)ethane

Compound	¹ H NMR δ (DMSO- d_6)				
	H-7, H-7′-	H-2, H-2′ H-6, H-6′	H-3, H-3′ H-5, H-5′		
1,2-bis(4- pyridyl) ethane	2.93 (s,4H)	8.51-8.57(dd, 4H)	7.072–7.083 (dd, 4H)		
1	3.50 (s,4H)	8.96 (d, 4H)	8.27 (d, 4H)		
2	3.48 (s,4H)	8.91 (d, 4H)	8.24 (d, 4H)		
3	3.54 (s,4H)	8.95 (d, 4H)	8.26 (d, 4H)		
4	3.51 (s,4H)	8.96 (d, 4H)	8.49 (d, 4H)		
5	3.47 (s,4H)	8.93 (d, 4H)	8.24 (d, 4H)		
6	3.54 (s,4H)	8.95 (d, 4H)	8.26 (d, 4H)		
7	3.45 (s,4H)	8.91(d, 4H)	8.20 (d, 4H)		
8	3.45 (s,4H)	9.11 (d, 4H)	8.21 (d, 4H)		
9	3.45 (s,4H)	9.00 (d, 4H)	8.23 (d, 4H)		
10	3.45 (s,4H)	9.01 (d, 4H)	8.24 (d, 4H)		
11	3.39 (s,4H)	9.10 (d, 4H)	8.17 (d, 4H)		

corresponding ylides, by deprotonation in basic medium, could be obtained by determination of their pk_a values. According to Ratts and co-workers,²⁴ the pK_a values of diquaternary salts could be used to estimate the nucleophilicity and hence reactivity of the corresponding vlides. Thus, the lower the salt pK_a value, the lower the vlide basicity and the higher its stability.



Scheme 3. Retrosynthetic strategy for indolizine formation.

Thus, the acid dissociation constants (pK_a) of four synthesized 1,2-bis(4-pyridyl)ethane diquaternary salts 1–4 were determined from UV-vis spectrometric data, using the method of Albert and Sergeant.²⁵ The investigated products were chosen in order to afford some correlations between the acid-basic equilibrium and salt's structures.

The method is based on the direct determination of the ratio of non-dissociated (protonated, salt) to dissociated (deprotonated, ylide) species in a series of non-absorbing buffer solutions. First the spectra of protonated and deprotonated molecules were obtained in an acid (hydrochloric acid) and in an alkali (sodium hydroxide) solution, in which compounds of interest would be present in either form. Next, the absorption spectra of each of the analyzed compounds in ten non-absorbing Britton-Robinson buffer solutions, with pH ranging from 5.31 to 11.84, with a constant ionic strength maintained with sodium chloride, were measured. From the absorbtion spectra, a set of ten pK_a values were obtained using Eq. (1):

$$pKa = pH + \log[(Di - D)/(D - Dm)]$$
(1)

where Dm and Di correspond to the optical density of protonated and deprotonated forms of compound, and D is the optical density in the buffer determined at analytical wave lengths.

The average value of the ten measurements was considered the $pK_{\rm a}$ of the diquaternary salt. The spectra used in spectrophotometric determination of pK_a value for salt **1** are reproduced in Fig. 1.



Fig. 1. Variation of UV–VIS spectrum of salt 1 (c=4·10⁻⁵ M) at different pH values.

The spectral data, the dissociation constant (pK_a) and acidic constant (K_a) of the analysed compounds are listed in Table 2. Some spectroscopic features of the analyzed compounds can be pointed out from the UV-vis spectra. Thus, the aqueous solutions of 1,2bis(4-pyridyl)ethane diquaternary salts 1-4 exhibit analogous continuous absorption spectra in the wavelength region 200-600 nm. The shape of their UV-vis spectra depends on the pH of the solution. Thus, in the pH range 1–9 for compounds **1–3** and, respectively, from 1 to 8 for compound 4, the absorption spectra present one single intense maximum at 250-265 nm $(\epsilon = 24,950 - 51,100 \text{ mol}^{-1} \text{ L cm}^{-1})$, deriving from the non-dissociated form of the compounds (Fig. 1, peak a). These UV absorption bands correspond to $\pi \rightarrow \pi^*$ transitions in the heterocyclic aromatic system. At higher pH values, this maximum decrease in intensity together with the appearance of a new band of lower intensity $(\varepsilon = 600 - 26,700 \text{ mol}^{-1} \text{ Lcm}^{-1})$ at 395–410 nm, which instantly begins to fall (Fig. 1, peak b). This unstable absorption band could be attributed to $n \rightarrow \pi^*$ transition within the dissociated 'zwitterionic' form, which appears in basic conditions. The rapid decrease of this band intensity suggests the instability of the 'zwitterionic' form, so the reversibility of the deprotonation reaction. The sharp isobestic points at 275–285 nm correspond to the acid–basic equilibrium (Scheme 4) and his presence indicates the fact that only two species have to be considered.

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Compound	pН	λ_{max}/nm	$\varepsilon (\mathrm{mol}^{-1}\mathrm{Lcm}^{-1})$	pK _a	Ka
no.	range				
1	1-9	250	44,750-39,750	$9.50{\pm}0.05$	3.16·10 ⁻¹⁰
	>9	250	39,200-34,300		
		395	950-6650		
2	1-9	265	51,100-50,000	$10.58{\pm}0.05$	$2.63 \cdot 10^{-11}$
	>9	265	44,400-25,975		
		400	1025-26,700		
3	1 - 9	255	34,075-32,175	$10.78{\pm}0.05$	$1.66 \cdot 10^{-11}$
	>9	255	33,225-24,950		
		400	600-14,025		
4	1-8	262	48,475-47,325	$8.65{\pm}0.05$	$2.24 \cdot 10^{-9}$
	>8	262	42,850-22,500		
		410	5550-25,725		

The pK_a value of the analyzed compounds was found to be in the range 8.65–10.78, which indicates a weak acidic character, similar to other pyridinium quaternary compounds.²⁶ The hydrogen atoms of the α -methylene group in the diquaternary salts are doubly activated by the carbonyl group and by the neighbouring positive charge of the pyridinium nitrogen. The values of dissociation constants pK_a are influenced by the presence of the phenyl radical and



Scheme 4. Acid-base equilibrium of 1,2-bis(4-pyridyl)ethane diquaternary salts.

its possible substituents, which differently promote delocalization of the negative charge of the ylide carbanion. Thus, the acidity of the salts is higher when the phenacyl-p-substituent has electronic withdrawing effects (-I and/or -E), which promote a supplementary delocalization of the anionic ylidic charge, and so a stabilization of the dissociated form.

The experimental findings also suggest that, as in the case of other bis-pyridinium salts,¹⁹ the 1,2-bis(4-pyridyl)ethane diquaternary salts can act as acid-base indicators in neutralization reactions due to their stability and the property of changing colour according to the pH: colourless in acid medium to yellow or orange in basic medium.

2.3. Thermogravimetric analysis

The thermal stability of selected compounds (**1**, **2**, **3**, **5**, **7** and **11**) was investigated through thermogravimetric analysis, and the relevant properties are reported in Table 3.

 Table 3

 Thermochemical properties of investigated N-quaternary salts

Compound	Mp (°C)	T_{dec} (°C)	$\Delta H (J/g)$
1	290-292	200	376.15
2	>350	270	237.14
3	300-302	250	17.37
5	302-304	200	246.42
7	330-332	260	326.47
11	250-251	220	209.08

 T_{dec} =onset of decomposition temperature.

The decomposition temperature (T_{dec}) indicates approximately when the salts start to degrade. It has been observed a notnegligible dependence on the substituent nature, i.e., the replacement in R₁ of a H by a OCH₃ or a Br, yields a significant increase of both decomposition and melting temperatures (endothermic peak).

The salts decomposition temperatures fall in the range 220–270 °C, suggesting a high stability of these molecules, the decomposition being likely due to their quaternary ammonium structures (Fig. 2). The first stage is a de-alkylation reaction, a process that can be regarded as the reverse of quaternization of 1,2-bis(4-pyridil)ethane. A polimerization process, before degrading into smaller components, is also evident, as confirmed by analysis of the black solid residue formed after each experiment. The compounds **1**, **5** and **11** are the salts with the lowest decomposition temperature, 200 and 220 °C, respectively. The compounds **7** and **2** exhibit the highest degradation temperature, 260 and 270 °C, respectively. The small drift at low temperature, in the case of **1** and **3**, is possibly related to moisture or to a negligible percentage of organic contaminant.

3. Conclusions

We report here the efficient synthesis of eleven new symmetric diquaternary salts derived from 1,2-bis(4-pyridyl)ethane, by



Fig. 2. TGA traces for 1 (pink), 2 (red), 3 (green), 5 (black), 7 (blue), 11 (orange).

quaternization of the nitrogen atoms with reactive halides. The acid-base properties for four of the synthesised salts were investigated through UV–vis spectrophotometric methods, revealing a weak acid behaviour of them and the property of changing colour according to the pH. TGA analysis was performed for six synthesized compounds, indicating the thermal stability of them up to around 200–270 °C. The characterization by thermal methods reveals the temperature range where the studied salts may be used and stored.

The obtained results and the structure of the newly synthesized derivatives suggest that the synthesized compounds could be suitable for using as synthons in cycloaddition reactions, as acidbase indicators or as electrochromic materials.

Attempts to obtain fluorescent bisindolizines starting from ones of the present 1,2-bis(4-pyridyl)ethane diquaternary salts were successfully made, using an efficient 1,3 dipolar cycloaddition method previously used by us for the synthesis of indolizine compounds starting from 4,4'-bipyridinium diquaternary salts. The results, unpublished yet, confirm the salts property to form the corresponding *N*-methynylide in basic conditions.

Since the quaternary ammonium salts are well known as antimicrobial agents, we also investigate the antimicrobial properties of synthesized 1,2-bis(4-pyridyl)ethane diquaternary salts. The compounds were found to exert a significant antimicrobial action against bacteria, yeasts and moulds.²⁷

4. Experimental

4.1. General

Melting points were recorded with a Büchi Melting Point B-540. ¹H NMR and ¹³C NMR spectra were recorded with a Bruker 400 Ultrashield (400 MHz) spectrometer operating at room temperature. Deuterated DMSO was used as solvent. Abbreviations for data quoted are: s, singlet; d, doublet; t, triplet; q, quartet; dd, doublet of doublets; m, multiplet. IR spectra were recorded from 4000 to 650 cm⁻¹ with a Perkin–Elmer Spectrum 100 instrument by total reflectance on a CdSe crystal. Elemental analyses (C, H, N) were performed with a Fisons Instruments 1108 CHNS-O elemental analyzer. Thermogravimetric analyses (TGA) were carried out in a N₂ stream with a Perkin-Elmer STA 6000 simultaneous thermal analyzer with heating rates from 5 to 10 °C/min. The electrospray ionization (ESI) mass spectra were measured on Thermo Scientific LC/MSQ Plus. Reagents used for synthesis were purchased from Aldrich, Fluka, and Merck companies. Organic solvents were purchased from Merck Company.

For determination of the dissociation constants (pK_a) freshly prepared aqueous solutions of the diquaternary salts were used. 30 μ L of salt stock solutions ($c=4 \cdot 10^{-3}$ M) were diluted to 3 mL in the spectrophotometer quartz cells with either 0.1 M hydrochloric acid, 0.1 M sodium hydroxide or the appropriate Britton-Robinson buffer solutions. The constant ionic strength of 0.1 M was maintained with sodium chloride. Britton-Robinson buffers were prepared by mixing 100 mL of a phosphoric, boric and acetic acid mixture (all 0.04 M) with different volumes of 0.2 M sodium hydroxide [***-Lange's Handbook of Chemistry, 12th ed., 1978]. UV-vis Beam PC 8 Scaning auto cell UVD-3200, Labomed spectrophotometer was use for spectrometric analysis. The absorption spectra were measured over the wavelength range of 200-600 nm with a reference to a blank solution. The 1 cm quartz cells were attached to a thermostatic water bath (Julabo) for maintaining the constant temperature (25±1.0 °C). The pH values of buffers were determined using a Multiparameter Consort C862. The pH-meter was calibrated at 25 °C using the three point calibration method with commercially available standard buffer solutions at pH 4.00, 7.00 and 10.00.

4.2. Synthesis

1,2-bis(4-pyridyl)ethane (2 mmol) and the corresponding halide derivatives (4.4 mmol) were heated in acetonitrile (20 mL) at reflux for 24 h. The mixture was cooled to room temperature, the solvent was removed by filtration and the obtained solid was washed with acetonitrile. The obtained compounds have a high purity level and do not necessitate further purification.

4.2.1. N,N'-diphenacyl-1,2-bis-(4-pyridinium)ethane dibromide (1). White—beige crystals; yield 92%; mp 290–292 °C. IR (ATR, cm⁻¹): 3009; 2948; 1691; 1637; 1594, 1570, 1518; 1228; 995. ¹H NMR (400 MHz, DMSO- d_6) δ /ppm: 8.96 (d, *J*=6.8 Hz, 4H), 8.27 (d, *J*=6.8 Hz, 4H), 8.09 (d, *J*=8.8 Hz, 4H), 7.82 (t, *J*=7.43 Hz, 2H), 7.69 (t, *J*=7.8 Hz, 4H), 6.48 (s, 4H: 2CH₂), 3.50 (s, 4H: 2CH₂). ¹³C NMR (75 MHz, DMSO- d_6) δ ppm: 190.78 (2*C*=0); 161.03 (2*C*); 145.72 (4C); 134.77 (2C); 133.49 (2C); 129.17 (4C); 128.23 (4C); 127.49 (4C); 65.64 (2CH₂); 33.74 (2CH₂). MS (ESI+), *m/z*: 421 (M²⁺-H⁺). Anal. Calcd for C₂₈H₂₆Br₂N₂O₂ (*M*_r=582.33 g/mol): C, 57.75; H, 4.50; N, 4.81. Found: C, 57.53; H, 4.68; N, 4.91.

4.2.2. N,N'-Di(*p*-bromophenacyl)-1,2-bis-(4-pyridinium)ethane dibromide (**2**). White crystals, yield 88%; mp>350 °C. IR (ATR, cm⁻¹): 3011; 2933, 2885; 1696; 1642; 1585, 1586; 1235; 1180; 990. ¹H NMR (400 MHz, DMSO-*d*₆) δ /ppm: 8.912 (d, *J*=6.4 Hz, 4H), 8.24 (d, *J*=6.4 Hz, 4H), 8.01 (d, *J*=8 Hz, 4H), 7.93 (d, *J*=8 Hz, 4H), 6.41 (s, 4H: 2CH₂), 3.48 (s, 4H: 2CH₂). ¹³C NMR (75 MHz, DMSO-*d*₆) δ /ppm: 193.52 (2C=O); 152.87 (2C); 148.44 (4C); 134.07 (2C); 131.76 (4C); 131.5 (4C); 128.973 (2C); 125.28 (4C); 65.79 (2CH₂); 33.53 (2CH₂). MS (ESI+), *m*/*z*: 579 (M²⁺-H⁺). Anal. Calcd for C₂₈H₂₄Br₄N₂O₂ (*M*_r=740.12 g/mol): C, 45.44; H, 3.27; N, 3.78. Found: C, 45.22; H, 3.22; N, 3.73.

4.2.3. N,N'-Di(p-methoxyphenacyl)-1,2-bis-(4-pyridinium)ethane dibromide (**3** $). White crystals, yield 94%, mp 300–302 °C. IR (ATR, cm⁻¹): 3004; 2958, 2835; 1674; 1636; 1599, 1571, 1556; 1230, 1028; 1170; 998. ¹H NMR (400 MHz, DMSO-<math>d_6$) δ /ppm: 8.95 (d, *J*=6.8 Hz, 4H), 8.26 (d, *J*=6.8 Hz, 4H), 8.05 (d, *J*=8.93 Hz, 4H), 7.21 (d, *J*=8.93 Hz, 4H), 6.37 (s, 4H: 2 CH₂), 3.88 (s, 6H: 20CH₃), 3.54 (s, 4H: 2 CH₂). ¹³C NMR (75 MHz, DMSO- d_6) δ /ppm: 190.64 (2 C=O); 161.05 (2C); 159.58 (2C), 145.70 (4C); 134.81 (2C); 130.45 (4C); 127.5 (4C); 123.66 (4C); 65.72 (2CH₂); 55.59 (CH₃: 0CH₃); 33.73 (2CH₂). MS (ESI+), *m/z*: 481 (M²⁺-H⁺). Anal. Calcd for C₃₀H₃₀Br₂N₂O₄ (*M*_r=642.38 g/mol): C, 56.09; H, 4.71; N, 4.36. Found. C, 55.73; H, 4.67; N, 4.20.

4.2.4. N,N'-Di(p-nitrophenacyl)-1,2-bis-(4-pyridinium)ethane dibromide (**4**). Beige crystals, yield 95%, mp 307–309 °C. IR (ATR, cm⁻¹): 3030; 2886, 2822; 1703; 1642, 1601; 1523, 1346; 1222, 1199–1181; 994. ¹H NMR (DMSO- d_6 , TMS) δ /ppm: 8.96 (d, *J*=6.8 Hz, 4H), 8.495 (d, *J*=6.8 Hz, 4H), 8.32–8.28 (m, 8H), 6.53 (s, 4H: 2CH₂), 3.51 (s, 4H: 2CH₂). ¹³C NMR (75 MHz, DMSO- d_6) δ /ppm: 190.21 (2C=O); 161.26 (2C); 150.63 (2C), 145.71 (4C); 138.20 (2C); 129.73 (4C); 127.57 (4C); 124.19 (4C), 65.89 (2CH₂); 33.77 (2CH₂). MS (ESI+), *m/z*: 511 (M²⁺-H⁺). Anal. Calcd for C₂₈H₂₄Br₂N₄O₆ (*M*_r=672.32 g/mol): C, 50.02; H, 3.60; N, 8.33. Found. C, 49.86; H, 3.67; N. 8.25.

4.2.5. *N,N'-Di(p-chlorophenacyl)-1,2-bis-(4-pyridinium)ethane* dichloride (**5**). White crystals, yield 94%, mp 302–304 °C. IR (ATR, cm⁻¹): 3011–3048; 2986–2887; 1694; 1643; 1589–1586, 1521; 1240, 1177, 1093; 991. ¹H NMR (400 MHz, DMSO-d₆) δ /ppm: 8.93 (d, *J*=6 Hz, 4H), 8.24 (d, *J*=6 Hz, 4H), 8.08 (d, *J*=8 Hz, 4H), 7.77 (d, *J*=8 Hz, 4H), 6.45 (s, 4H: 2 CH₂), 3.47 (s, 4H: 2 CH₂). ¹³C NMR (75 MHz, DMSO-d₆) δ /ppm: 190.58 (2*C*=O); 161.13 (2C); 157.20 (2C), 147.78 (4C); 141.20 (2C), 132.17 (4C); 131.37 (4C); 129.53 (4C); 65.74 (2CH₂); 33.78 (2CH₂). MS (ESI+), *m/z*: 490 (M²⁺-H⁺). Anal. Calcd for C₂₈H₂₄Cl₄N₂O₂ (*M*_r=562.31 g/mol): C, 59.81; H, 4.30; N, 4.98. Found: C, 59.45; H, 4.32; N, 5.09.

4.2.6. *N*,*N*'-*Di*(*m*-*methoxyphenacyl*)-1,2-*bis*-(4-*pyridinium*)*ethane dibromide* (**6**). White crystals, yield 90%, mp 302–303 °C. IR (ATR, cm⁻¹): 3008; 2951; 1690; 1639; 1597–1581; 1263, 1194–1220; 998. ¹H NMR (400 MHz, DMSO-*d*₆) δ /ppm: 8.95 (d, *J*=6.8 Hz, 4H), 8.26 (d, *J*=6.8 Hz, 4H), 7.69–7.55 (m, 6H), 7.41–7.38 (m, 2H), 6.46 (s, 4H: 2CH₂), 3.88 (s, 6H: 2OCH₃), 3.54 (s, 4H: 2CH₂). ¹³C NMR (75 MHz, DMSO-*d*₆) δ /ppm: 190.64 (2*C*=O); 161.05 (2*C*); 159.58 (2*C*), 145.70 (4*C*); 134.81 (2*C*); 130.45 (2*C*); 127.5 (4*C*); 120.66 (2*C*); 120.49 (2*C*), 112.94 (2*C*); 65.72 (2*C*H₂); 55.59 (CH₃: OCH₃) 33.73 (2CH₂). MS (ESI+), *m/z*: 481 (M²⁺-H⁺). Anal. Calcd for C₃₀H₃₀Br₂N₂O₄ (*M*_r=642.38 g/mol): C, 56.09; H, 4.71; N, 4.36. Found. C, 55.93; H, 4.88; N. 4.31.

4.2.7. N,N'-Di(3,4-dihydroxyphenacyl)-1,2-bis-(4-pyridinium)ethane dichloride (7). White crystals, yield 82%, mp 330–332 °C. IR (ATR, cm⁻¹): 3059–2737; 1681; 1638; 1606–1593, 1518; 1342; 1291, 1167; 1131.39. ¹H NMR (400 MHz, DMSO- d_6) δ /ppm: 10.38 (s, 2H: 2OH), 9.67 (s, 2H: 2OH), 8.91(d, *J*=6 Hz; 4H), 8.20 (d, *J*=6 Hz; 4H), 7.47–7.43 (m, 4H), 6.98 (d, *J*=8 Hz, 2H), 6.31 (s, 4H: 2CH₂), 3.45 (s, 4H: 2CH₂). ¹³C NMR (75 MHz, DMSO- d_6) δ /ppm: 188.64 (2C=O); 160.77 (2C); 152.30 (2C), 149.40 (2C), 145.68 (2C); 145.53 (2Ct); 127.33 (4C); 123.98 (4C); 115.51 (2C), 114.95 (2C), 65.12 (2CH₂); 33.37 (2CH₂). MS (ESI+), *m/z*: 485 (M²⁺-H⁺). Anal. Calcd for C₂₈H₂₆Cl₂N₂O₆ (*M*_r=557.42 g/mol): C, 60.33; H, 4.70; N, 5.03. Found: C, 59.99; H, 4.74; N, 4.93.

4.2.8. N,N'-Di(5-bromo-2-hydroxy-propiophenacyl)-1,2-bis-(4pyridinium)ethane dibromide (**8**). White—rose crystals, yield 81%, mp 262–263 °C. IR (ATR, cm⁻¹): 3116–2903; 1667; 1635; 1591, 1474, 1466, 1407; 1285; 1169; 988. ¹H NMR (400 MHz, DMSO-d₆) δ / ppm: 11.57 (s, 2H: 2OH), 9,11 (d, *J*=8 Hz, 4H), 8.21 (d, *J*=8 Hz, 4H), 7.82 (s, 2H), 7.70 (m, 2H), 7.09 (d, *J*=8 Hz, 2H), 6.66 (q, 2H: 2CH), 3.45 (s, 4H: 2CH₂), 1.95 (d, 6H: 2CH₃). ¹³C NMR (75 MHz, DMSO-d₆) δ /ppm: 193.03 (2C=O); 161.40 (2C); 157.22 (2C), 145.00 (4C); 138.12 (2C); 132.68 (2C); 126.97 (4C); 122.51 (2C), 120.08 (2C), 110.74 (2C), 73.18 (2CH); 33.817 (2CH₂); 16.87 (2CH₃). MS (ESI+), *m*/ *z*: 639 (M²⁺-H⁺). Anal. Calcd for C₃₀H₂₈Br₄N₂O₄ (*M*_r=800.17 g/mol): C, 45.03; H, 3.53; N, 3.50. Found: C, 44.92; H, 3.65; N, 3.42.

4.2.9. N,N'-Di(carbomethoxy-methyl)-1,2-bis-(4-pyridinium)ethane dibromide (**9**). White crystals, yield 98%, mp 181–182 °C. IR (ATR, cm⁻¹): 3007; 2951; 1737; 1641; 1570, 1521; 1230–1201; 994. ¹H NMR (400 MHz, DMSO- d_6) δ /ppm: 9.00 (d, *J*=6.8 Hz, 4H), 8.23 (d, *J*=6.8 Hz, 4H'), 5.68 (s, 4H: 2CH₂), 3.79 (s, 6H: 2 OCH₃), 3.45 (s, 4H: 2 CH₂). ¹³C NMR (75 MHz, DMSO- d_6) δ /ppm: 166.97 (2C=Oester);

161.50 (2C); 145.67 (4C); 127.48 (4C); 59.63 (2CH₂); 53.14 (2CH₃: OCH₃); 33.66 (2CH₂). MS (ESI+), m/z: 329 (M²⁺-H⁺). Anal. Calcd for C₁₈H₂₂Br₂N₂O₄ (M_r =490.19 g/mol): C, 44.10; H, 4.52; N, 5.71. Found: C, 43.93; H, 4.60; N, 5.66.

4.2.10. N,N'-Di(carboethoxy-methyl)-1,2-bis-(4-pyridinium)ethane dibromide (**10**). White—rose crystals, yield 85%, mp 191–192 °C. IR (ATR, cm⁻¹): 3006; 2941; 1725; 1639; 1571, 1521; 1234–1197; 1010. ¹H NMR (400 MHz, DMSO-d₆) δ /ppm: 9.01 (d, *J*=6.8 Hz, 4H), 8.24 (d, *J*=6.8 Hz, 4H), 5.67 (s, 4H: 2CH₂), 4.25 (q, *J*=7.1 Hz, 4H: 2 CH₂), 3.45 (s, 4H: 2 CH₂), 1.27 (t, *J*=7.1 Hz, 6H: 2 CH₃). ¹³C NMR (75 MHz, DMSO-d₆) δ /ppm: 166.47 (2*C*=Oester); 161.45 (2C); 145.66 (4C); 127.47 (4C); 62.30 (2CH₂); 59.66 (2CH₂: OCH₂); 33.67 (2CH₂); 13.94 (2CH₃). MS (ESI+), *m/z*: 357 (M²⁺–H⁺). Anal. Calcd for C₂₀H₂₆Br₂N₂O₄ (FW=518.24 g/mol): C, 46.35; H, 5.06; N, 5.41. Found: C, 46.23; H, 5.19; N, 5.34.

4.2.11. N,N'-Di(5'-nitrofuran-methylen)-1,2-bis-(4-pyridinium)ethane dibromide (**11**). Beige crystals, yield 85%, mp 250–251 °C. IR (ATR, cm⁻¹): 3033–3013; 2952–2920; 1636; 1536; 1501, 1351; 1234, 1161; 1015. ¹H NMR (400 MHz, DMSO- d_6) δ /ppm: 9.10 (d, *J*=6.4 Hz; 4H), 8.17 (d, *J*=6.4 Hz; 4H), 7.75 (d, *J*=3.6 Hz, 2H), 7.18 (d, *J*=3.6 Hz; 2H), 6.05 (s, 4H: 2 CH₂), 3.39 (s, 4H: 2 CH₂). ¹³C NMR (75 MHz, DMSO- d_6) δ /ppm: 152.05 (2C); 150.45 (2C); 146.57 (4C); 130.24 (4C); 117.94 (2C), 115.64 (2C), 56.94 (2CH₂); 35.80 (2CH₂). MS (ESI+), *m/z*: 435 (M²⁺-H⁺). Anal. Calcd for C₂₂H₂₀Br₂N₄O₆ (*M*_r=596.23 g/mol): C 44.30; H 3.38; N 9.40. Found C. 44.59; H. 3.35; N. 9.10.

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