REACTION PRODUCTS OF 1,3-INDANDIONE WITH HETERO-AROMATIC CARBALDEHYDES: SYNTHESIS, STRUCTURE AND NMR-INVESTIGATIONS[1]

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Abstract - The synthesis of 1:1 condensation products from 1,3-indandione and various heteroaromatic carbaldehydes is described. Employment of aldehydes derived from π-deficient *N*-heteroaromatics was found to lead also to 2:1 adducts *via* Michael-addition of the 1,3-diketone to the initially formed 1:1 condensation products. ^{1}H and ^{13}C nmr spectroscopic studies of the products obtained and of known congeners are presented. The structure of the 2:1 adduct resulting from reaction of 1,3-indandione and 4-quinolinecarbaldehyde was determined by X ray analysis.

INTRODUCTION

The 1,3-indandione moiety (**1**) represents a substructure of several biologically active compounds.[4] Amongst them, 2-methylene derivatives of **1** are an interesting class of compounds as, for instance, 2-(*N,N*-dimethylaminomethylene)-1,3-indandione can act as a diuretic[5] and some pyridinylmethylene derivatives have been reported to exhibit anticoagulant activity.[6] Moreover, compounds of this type are valuable starting products in the construction of complex ring systems employing cycloaddition[7] or cyclocondensation[8] reactions. The preparation of such (hetero)arylmethylene-1,3-indandiones usually is achieved *via* condensation of 1,3-indandione (**1**) with an appropriate aromatic aldehyde. However, this approach cannot be generalized. For instance, it has been shown that with 3- and 4-pyridazinecarbaldehydes the reactions do not end up with the formation of 1:1 condensation products, but that the latter compounds - which are excellent Michael acceptors - can be attacked by another indandione molecule to afford 2:1 products.[9] In the light of these findings we now investigated the reactions of 1,3-indandione (**1**) with a variety of heteroaromatic aldehydes. Moreover, spectroscopic studies with the compounds thus obtained and with known congeners were performed in order to elucidate structural, conformational and electronic properties of 2-heteroarylmethylene-1,3-indandiones and their Michael reaction products.

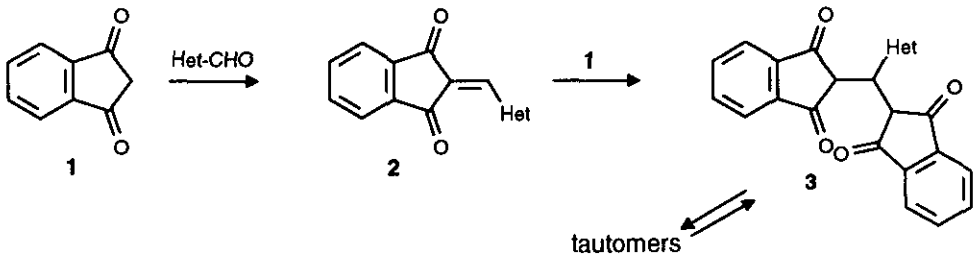
RESULTS AND DISCUSSION

Synthesis

Scheme 1 gives a survey of the reactions carried out in the course of the present study. In general, equimolar amounts of 1,3-indandione (**1**) and the appropriate heteroaromatic aldehyde were reacted in ethanol, methanol or dichloromethane solution in a Knoevenagel type mode leading to either condensation products of type (**2**) or to Michael adducts of type (**3**).

Refluxing **1** and 1-methylpyrrol-2-carbaldehyde in ethanol afforded the condensation product (**2a**) even in the absence of a catalyst; interestingly, in dichloromethane solution no reaction can be observed. Compounds (**2b**)[10] and (**2c**)[11] were prepared according to known procedures (refluxing **1** and the suitable

Scheme 1



2,3	Het
a	1-Methyl-2-pyrrolyl
b	2-Furanyl
c	2-Thienyl
d	5-Methyl-2-thienyl
e	5-Nitro-2-thienyl
f	5-Bromo-2-thienyl
g	3-Thienyl
h	3-Pyrazolyl
i	1-Benzyl-4-pyrazolyl
j	2-Imidazolyl

2,3	Het
k	3-Indolyl
l	4-Oxo-4*H*-[1]benzopyran-3-yl
m	2-Pyridinyl
n	3-Pyridinyl
o	4-Pyridinyl
p	2-Quinolinyl
q	4-Quinolinyl
r	3-Pyridazinyl
s	4-Pyridazinyl

carbaldehyde in ethanol with piperidine as catalyst). In an analogous manner the novel thiophene derivatives (**2d-2g**) and the diazole derivatives (**2h-2j**) were obtained. The only moderate yields of compounds (**2d**) and (**2i**) result from purification problems encountered in attempts to obtain material sufficiently pure for CHN-analysis. The synthesis of compounds (**2k**)[12] and (**2l**)[13] by carrying out the reaction in refluxing ethanol with piperidine as catalyst has been already described; we now found that nearly identical yields are obtained when these reactions are performed at room temperature and in the absence of a catalyst.

An interesting case is the behaviour of **1** with 2-pyridinecarbaldehyde: here the formation of a simple condensation product (**2m**) could never be observed even if the reaction conditions (molar ratio, catalyst, solvent, temperature) were systematically varied. Instead, performance of the reaction at room temperature in ethanol in the absence of a catalyst leads to a yellow powder with the molecular formula $C_{24}H_{15}NO_4$ (mp 161-163°C), for which - according to nmr spectroscopic data (see below) - structure (**3m-A**) (Scheme 3) is proposed. On the other hand, a deep-red product of identical elemental

composition, however with mp 270-272°C, is obtained upon reaction in dichloromethane at 4°C. For this compound we propose structure (**3m-B**) (Scheme 3). The assumption that these two compounds are tautomers is not only based on analytical and ms data but also results from the fact that oxidation processes in the course of the reaction were ruled out by degassing the solutions of the reaction partners and working under an Argon atmosphere. Moreover, compound (**3m-A**) is partially converted to **3m-B** upon recrystallization from ethanol - isopropanol, and a DMSO-d_6 solution of **3m-A** showed a ^{1}H-nmr spectrum identical with that of **3m-B** after standing for one day at room temperature. Despite much effort spent we failed in producing sufficiently large crystals of **3m-A** and **3m-B** for X ray analysis.

In contrast, reactions of **1** with 3-pyridinecarbaldehyde and 4-pyridinecarbaldehyde, respectively, in ethanol afford the expected condensation products (**2n**)[6] and (**2o**)[6,14] in good yields. However, we found that in dichloromethane solution **1** and 4-pyridinecarbaldehyde exclusively reacted to a 2:1 adduct (**3o**) existing as a bis-enol in DMSO-d_6 solution as displayed in Scheme 3. Treatment of 2-quinolinecarbaldehyde with **1** in ethanol also leads to a Michael-addition compound (**3p**) as the sole product. A similar reaction behaviour is observed with 4-quinolinecarbaldehyde and **1** in dichloromethane (formation of **3q**). Upon recrystallization of the latter compound from 2-butanone suitable material for X ray analysis could be obtained, the interesting structural features of compound (**3q**) are described below. 3-Pyridazinecarbaldehyde and **1** again led to the formation of a compound of type (**3**), the resulting dark violet-red compound is assumed to have structure (**3r**) in DMSO-d_6 solution (Scheme 3) on basis of its nmr data. The reaction of **1** with 4-pyridazinecarbaldehyde has been described previously:[9] in ethanol the Michael adduct (**3s**) (Scheme 3) is formed exclusively, switching to dichloromethane as the solvent leads to the condensation product (**2s**).

In conclusion, Knoevenagel type reactions of **1** with carbaldehydes derived from π-excessive heteroaromatics are characterized by the exclusive formation of condensation products of type (**2**). In contrast, with carbaldehydes of π-deficient *N*-heteroaromatics having the formyl group in α-position to the ring nitrogen atom no condensation products can be isolated. Here Michael adducts of type (**3**) are the sole reaction products. Carbaldehydes derived from π-deficient heteroaromatics having the formyl group in β- or γ-position to the ring nitrogen atoms represent 'borderline'-cases as here both possible products can be obtained depending on the reaction conditions. Thus, reaction of **1** with 3-pyridinecarbaldehyde gives **2n**, whereas with 4-pyridinecarbaldehyde and 4-pyridazinecarbaldehyde compounds (**2o**) and (**3o**), or (**2s**)

and (**3s**), respectively, are obtained. In contrast, from 4-quinolinecarbaldehyde we only could isolate the 2:1-product (**3q**) under the reaction conditions chosen.

Spectroscopic Investigations and Conformational Analysis

2-Heteroarylmethylene-1,3-indandiones of Type (2)

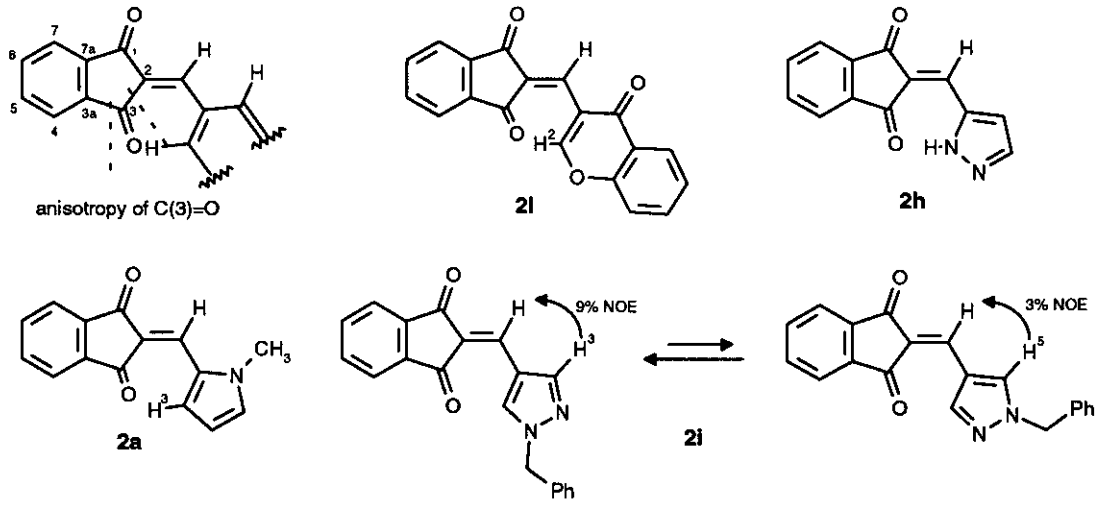
The ir spectra of compounds (**2**) are characterized by the occurence of two carbonyl absorptions in the range of 1705-1730 cm^{-1} and 1660-1690 cm^{-1}, with the two bands separated by 30-50 cm^{-1}. This is in accordance with reports in the literature[15] assigning the two different signals to the symmetrical (higher frequency) and asymmetrical (lower frequency) stretching mode of the carbonyl groups.

A consistent fragmentation behaviour can be observed in the electron-impact mass spectra of compounds (**2**): in many cases the parent peak is also the base peak, other peaks with high relative intensity are M^+-1, M^+-28 (CO), M^+-56 (2CO), 104 ($C_7H_4O^+$) and 76 ($C_6H_4^+$).

The ^1H nmr spectra of compounds (**2**) in $CDCl_3$ solution exhibit a characteristic singlet signal between 7.70 and 8.05 ppm for the alkene proton. Only for compound (**2l**) a markedly higher resonance frequency (8.44 ppm) was observed for the latter signal, which can be easily explained by deshielding due to the spatially close chromone C=O group in the most stable conformation (Scheme 2). At 300 MHz spectrometer frequency, the aromatic protons of the indene system (indene H-4,5,6,7) usually are split in two groups of signals (each with relative intensity 2) with that of H-4 and H-7 at lower field. This assignment was unambiguously confirmed by long-range INEPT experiments with selective excitation[16] or on basis of HMBC spectra[17] as H-7 and H-4 show a correlation with the two carbonyl carbon atoms indene C-1 (*E* to the heteroaroamtic substituent) and C-3 (*Z* to the heteroaromatic substituent), respectively, due to a vicinal $^{13}C,^1H$ coupling. An exception from the above mentioned trend was observed for the pyrazole derivative (**2h**). With this compound the resonances of indene H-4 and indene H-7 give rise to two separated signals. This phenomenon can be explained by the fact that in $CDCl_3$ the pyrazole NH is obviously involved in an intramolecular hydrogen bond with the carbonyl oxygen attached at indene C-3 (Scheme 2) leading to a different influence of the carbonyl groups on the adjacent protons H-4 and H-7. MO Calculations (AM1,[18] SAM1[19])[20] confirm this assumption, as the species with the intramolecular

hydrogen bond is energetically more favoured than other forms of **2h** (Table 2). A similar trend was found with the 2-imidazolyl derivative (**2j**), for which we also propose intramolecular hydrogen bonding of the azole NH in $CDCl_3$, however, the observed chemical shift difference between indene H-4 and H-7 is somewhat smaller than that found in the spectrum of **2h**. Moreover, a remarkable symptom in the ^{1}H-nmr spectra of compounds (**2**) is the marked low-field shift of heteroaromatic protons attached to the carbon atoms in α-position to the indandionemethylene substituent. Thus, for instance, pyrrole H-3 in **2a** has a chemical shift of δ 8.62 ppm (this is a 1.72 ppm low field shift compared to the corresponding signal in 1-methylpyrrol-2-carbaldehyde with $\delta_{H\text{-}3}$ 6.90 ppm), in compound (**2l**) the chromone H-2 signal resonates even at 10.39 ppm ($\delta_{H\text{-}2}$ in chromone-3-carbaldehyde 8.55 ppm). This can be attributed to the anisotropy effect of the indane C(3)=O group coming close to the mentioned α-protons in the most stable conformation(s) (Scheme 2). Unambiguous assignments of the heteroaromatic protons were achieved by chemical shift and coupling considerations as well as based on COSY and 1D TOCSY[21] experiments.

Scheme 2



To determine preferred conformations as well as to get insight into the electronic situation of compounds (**2**), MO calculations (geometry optimizations with the AM1[18] and SAM1[19] method) were carried out with **2a-c**, **2g-l**, **2n**, **2o**, and **2s**; in Table 2 the results of these calculations are summarized. Using the SAM1 method always minimized structures with the heteroaromatic system and the indandionemethylene moiety

being coplanar were obtained. Employing the AM1 hamiltonian in general shows the same trends that emerge with the SAM1 method, however, in some cases the most stable conformers exhibit distorsions (~ 20 - 40 deg.) between the planes of the heteroaromatic and the indandionemethylene system (compounds **2l**, **2n**, **2o**, **2s**). The obtained results agree well with the observations regarding the ^{1}H nmr spectra. For instance, from the MO calculations the depicted (Scheme 2) structure of **2l** turned out as the only stable one, the "fixed" proximity of alkene-H to the chromone C=O and that of chromone H-2 to the indane C(3)=O results in marked low-field shifts of the involved protons. With other congeners (e.g. **2c**, **2n**, **2o**, **2s**), the differences in energy between the two possible coplanar conformations and/or the rotational barriers are not very high, leading to a somewhat reduced influence of the anisotropic C(3)=O group on the heteroaromatic α-protons and thus to a reduced deshielding of the latter. On the other hand, large differences in the heats of formation were found for conformers (and tautomers) of azole derivatives (**2h**) and (**2j**) proving the species with intramolecular hydrogen bond to be much more stable. Additionally, on basis of NOE difference experiments some informations regarding conformational preferences could be otained. Thus, for instance, irradiation of the pyrazole H-3 transition of compound (**2i**) gives the alkene-H signal a much larger NOE (~ 9%) than irradiation of the pyrazole H-5 resonance does (~ 3% NOE) under analogous conditions (Scheme 2). This is a hint for the predominance of the conformer with the alkene-H and pyrazole H-3 in "cis" position which is confirmed by the MO calculations (AM1 as well as SAM1 show a ~ 2 kcal/mol gain for the latter species compared to the reverse conformer, Table 2). With compound (**2l**), no NOE on the alkene-H signal could be detected upon irradiation of chromone H-2 and, reversely, no on chromone H-2 when saturating the alkene-H transition. Again, this supports the assumption that **2l** is exclusively present in the conformation with the above mentioned protons having a torsion angle of 180 degrees. Similar NOE experiments were carried out with compounds (**2k**, **2n**, and **2s**) all confirming the conformational preferences derived from the MO calculations. Moreover, it should be mentioned that NOE difference experiments (irradiation of suitable protons attached on the heteroaromatic system) in some cases (e.g. **2a**) enabled us to identify the alkene-H resonance when the latter line was overlapped by indene-H signals in the normal ^{1}H-nmr spectrum.

The ^{13}C nmr data of compounds (**2**) are summarized in Table 1. Unambiguous assignments were obtained on basis of coupling information derived from APT spectra and fully ^{1}H-coupled ^{13}C nmr spectra (gated decoupling), by HMQC[17] and HMBC[17] experiments, by 1D HETCOR[22] as well as by long-range INEPT

Table 1: ^{13}C Nmr chemical shifts (δ, ppm) of compounds (**2**)

No.	sol-vent[a]	indene-C C-1[b]	C-3[c]	C-7a, C-3a[d]	C-6, C-5[d]	C-7, C-4[d]	C-2[e]	alkene-C f	C of heteroaromatic system and attached substituents
2a	A	191.3	189.2	142.4, 140.0	134.4, 134.0	122.5, 122.4	121.1	129.1	133.6 (5), 130.3 (2), 125.9 (3), 111.9 (4); 34.6 (NMe)
2b	A	189.9	188.9	142.4, 140.4	135.1, 134.8	123.1, 122.9	124.8	129.2	151.4 (2), 149.0 (5), 124.7 (3), 114.5 (4)
2c	A	190.2	189.3	142.1, 140.4	135.1, 134.9	123.1, 123.0	124.8	136.1	141.5 (3), 138.1 (5), 137.4 (2), 128.6 (4)
2g	A	190.5	189.1	142.3, 140.1	135.2, 134.9	123.1, 123.1	126.9	137.5	138.5 (2), 136.0 (3), 131.9 (4), 126.2 (5)
2h	A	191.2	188.9	141.7, 140.8	136.0, 135.6	123.8, 123.5	127.6	128.7	141.4 (5), 137.5 (3), 115.4 (4)
	B	189.4	188.6	141.7, 139.6	135.8, 135.6	122.9, 122.9	127.0	136.1	146.1 (3(5)), 130.8 (5(3)), 110.6 (4)
2i	A	190.3	189.9	142.1, 140.2	134.9, 134.7	123.0, 122.7	125.3	135.1	146.2 (3), 136.2 (5), 117.8 (4); 135.2 (Ph C-1), 129.0 (Ph C-3,5), 128.5 (Ph C-4), 127.9 (Ph C-2,6); 56.7 (NCH_2)
2j	A	191.8	188.8	141.4, 140.6	135.9, 135.2	123.4, 123.3	125.9	132.1	144.0 (2), 135.9 (4), 121.9 (5)
	B	190.7	188.7	141.0, 139.9	136.1, 135.8	123.1, 122.9	125.3	129.9	142.5 (2)
2k	B	189.9	189.3	141.2, 139.1	134.6, 134.4	122.0, 121.8	121.0	135.0	138.1 (2), 136.5 (7a), 128.1 (3a), 123.4 (6), 122.3 (5), 117.9 (4), 112.9 (7), 112.2 (3)
2l	A	190.2	189.0	142.1, 140.4	135.6, 135.4	123.5, 123.4	129.3	136.5	175.3 (4), 163.4 (2), 156.1 (8a), 134.5 (7), 126.7 (5), 126.3 (6), 124.0 (4a), 118.6 (3), 118.5 (8)
2n	A	189.1	188.5	142.3, 140.1	135.5, 135.4	123.4, 123.4	131.2	142.2	154.7 (2), 152.7 (6), 139.6 (4), 128.9 (3), 123.5 (5)
	B	188.8	188.4	141.9, 139.6	136.1, 136.0	123.2, 123.1	131.2	141.4	154.0 (2), 152.5 (6), 139.5 (4), 128.7 (3), 123.5 (5)
2o	A	188.8	188.1	142.6 140.2	135.9, 135.8	123.7, 123.6	133.1	142.6	150.5 (2,6), 139.1 (4), 125.6 (3,5)
	B	188.3	188.0	142.3, 139.3	136.2, 136.2	123.3, 123.3	133.3	141.3	150.0 (2,6), 139.9 (4), 125.5 (3,5)
2s	A	187.9	187.9	142.6, 140.5	136.3, 136.3	124.0, 124.0	135.8	138.3	151.9 (3), 151.8 (6), 130.1 (4), 127.0 (5)
	B	187.9	187.9	142.0, 140.0	136.4, 136.4	123.4, 123.4	135.2	137.6	151.8 (6), 151.5 (3), 130.4 (4), 127.3 (5)

[a] A: $CDCl_3$; B: DMSO-d_6

[b] ^3J(C1,H7) = 3.0 - 3.3 Hz; ^3J(C1,alkene-H) = 5.7 - 6.2 Hz.

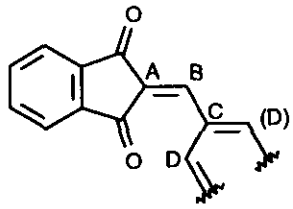
[c] ^3J(C3,H4) = 3.0 - 3.1 Hz; ^3J(C3,alkene-H) = 9.6 - 10.4 Hz.

[d] An unambiguous distinction between the two carbon atoms was not possible, the indicated order is assumed.

[e] ^2J(C2,alkene-H) in Hz: **2a**: 4.3, **2b**: 3.9, **2c**: 3.3, **2g**: 3.3, **2h**: 3.0 (DMSO-d_6), **2i**: 3.3, **2k**: 3.0, **2n**: 3.6 ($CDCl_3$), **2o**: 3.6 ($CDCl_3$), **2s**: 3.7 ($CDCl_3$).

[f] ^1J (Hz): **2a**: 147.8, **2b**: 155.4, **2c**: 155.2, **2g**: 153.4, **2h**: 160.4 ($CDCl_3$) and 153.6 (DMSO-d_6), **2i**: 153.1, **2j**: 160.3 ($CDCl_3$), **2k**: 149.1, **2l**: 159.6, **2n**: 154.1 ($CDCl_3$), **2o**: 155.9 ($CDCl_3$), **2s**: 158.0 ($CDCl_3$).

Table 2. Optimized structures of compounds (**2**)



		AM1		SAM1	
No.	atom D	ΔH_f (kcal/mol)	Φ_{ABCD}*	ΔH_f (kcal/mol)	Φ_{ABCD}*
2a	pyrrole N-1	37.05	180	10.08	180
		38.00	40	12.82	42
2b	furan O-1	-3.06	181	-21.34	180
		-0.45	0	-17.06	0
2c	thiophene S-1	20.14	182	9.10	-180
		20.33	0	8.39	0
2g	thiophene C-2	19.27	-1	10.84	0
		20.36	-200	11.74	180
2h	pyrazole N-2	54.46	0	25.95	0
		59.32	184	30.88	-180
2i	pyrazole C-3	86.30	179	51.75	179
		88.18	0	53.86	0
2j	imidazole N-1	41.25	-1	19.20	0
		48.29	-140	--	--
2k	indole C-2	43.27	0	16.67	0
2l	chromone C-2	-28.90	24	-59.26	0
2n	pyridine C-2	26.19	-148	8.79	-180
		26.66	35	8.95	0
2o	pyridine C-3	27.45	39	10.25	0
2s	pyridazine C-3	50.42	-170	25.68	180
		50.93	37	26.04	0

* Φ_{ABCD} (degrees): A = indane C-2; B = alkene-C; C = ipso-C of heteroaroamtic system; D = atom D as given in column 2

spectra with selective DANTE excitation.[16] Discrimination of the carbonyl-C resonances indene C-1 and indene C-3 (δ 188 - 192 ppm) was achieved on basis of their vicinal coupling to the alkene-H: the signal at lower frequency was identified as indene C-3 for it is characteristically more split than that of C-1 due to its "trans" coupling ^3J(C-3,alkene-H) ~ 10 Hz, which is markedly larger than the corresponding "cis"-coupling ^3J(C-1,alkene-H) ~ 6 Hz. The unambiguous discrimination between the signals of indene C-3a and C-7a, between indene C-4 and C-7, and between indene C-5 and C-6 would require 2D INADEQUATE experiments which were not possible owing to the low solubilty of compounds (**2**). However, it is fairly probable that within the mentioned pairs of resonances the signal with the smaller chemical shift originates from the carbon atom being "cis" to the heteroaromatic substiuent (C-3a, C-4, C-5) due to the shielding effect of the latter.

Michael Addition Products of Type (3)

Whereas condensation products (**2**) exhibit very homogenous spectroscopic data this is not the case for compounds of type (**3**). One common feature is the fact that in the EI-mass spectra of compounds (**3**) the molecular ion peak has only low relative intensity (< 3%). On the other hand, compounds (**3m-B**, **3p**, and **3r**) are characterized by intensive M^+-1 and M^+-2 peaks. The simultaneous occurence of peaks M^+-146 (= M^+-indandione) and 146 with **3m-A**, **3o**, **3q**, and **3s**[9] indicates a fragmentation path *via* retro-Michael reaction. Also the ir spectra of **3o**, **3q**, and **3s**[9] show some consistency as they contain two different carbonyl bands similar to compounds (**2**).

The ^1H nmr spectra of compounds (**3m**) are strongly dependent from temperature, concentration and spectrometer frequency used. The 300 MHz spectra of **3m-A** and **3m-B** in DMSO-d_6 are characterized by strong line broadenings indicating a dynamic behaviour with rates in the range of the nmr timescale, at 80 MHz sometimes more narrow signals were obtained. Whereas the yellow compound (**3m-A**) exhibits a signal of relative intensity 1 in the aliphatic region (~ 5.2 ppm), which can be assigned to a CH-fragment between the two indene systems and the pyridine ring, the dark-red **3m-B** has only resonances with δ > 7.4 and thus conjugation of the ring systems over an central sp^2-carbon atom can be assumed here. The observation that a DMSO-d_6 solution of **3m-A** turns to intensive red and then shows a spectrum identical to that of **3m-B** after standing at room temperature for some time and, additionally, that both compounds

have identical spectra under certain conditions prove the two compounds to be easily interconvertable. The ^{13}C-nmr spectra of compounds (**3m**) are characterized by the simultaneous occurence of more than two (at least four) tautomeric forms and thus were not interpretable for us. However, the fact that also the complete signal set of **1** could be detected in the ^{13}C-nmr spectra of **3m** (the same applies for those of **3p** and **3r**) indicates that for these compounds retro-Michael reactions obviously play a role within the equilibration processes in solution.

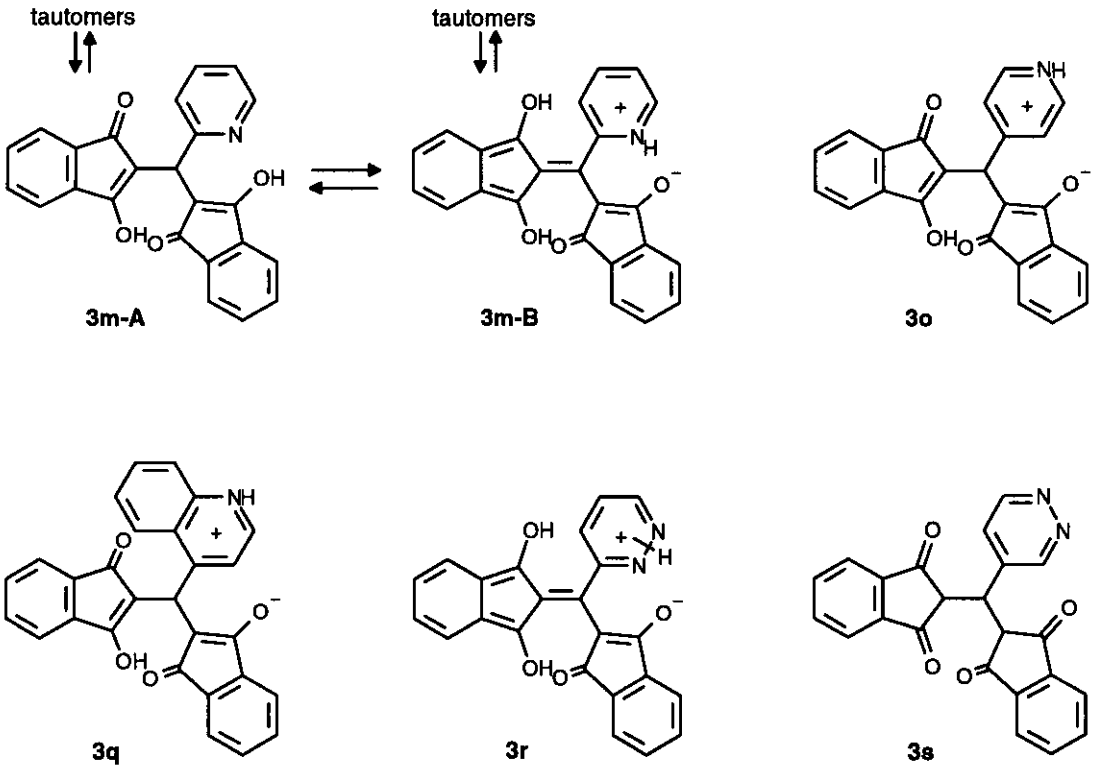
In contrast to compounds (**3m**) the spectra of the 4-pyridine derivative (**3o**) show only one set of signals. The occurrence of a singlet at δ 5.25 ppm ($\delta_{C\text{-}H}$ 30.5 ppm) proves a central CH-substructure (this agrees with the fact that **3o** is nearly colorless) which is confirmed by NOE difference experiments (strong NOE on pyridine H-3/5 upon irradiation of the above resonance) as well as by HMBC spectra (long-range connection between C-H and pyridine C-3/5 as well as pyridine C-4). Moreover, the ^{13}C chemical shifts of the pyridine system in **3o** closely resemble those of a pyridinium ion (relative high-field shift of pyridine C-2/6, low-field shift of pyridine C-4 compared to the parent azine ring) giving a strong hint that the pyridine nitrogen atom in **3o** is protonated. The fact that the two (different) indene units in compound (**3o**) give rise to only one set of signals (^{1}H, ^{13}C) can be explained by rapid exchange between equivalent tautomers. The ^{13}C-chemical shifts of the indene-C atoms resemble closely to those found for the enol form of 2-phenyl-1,3-indandione in DMSO-d_6 solution.[23] It should be mentioned that a DMSO-d_6 solution of **3o** turns to violet on standing and the occurence of additional species can be detected.

Whereas the spectroscopic properties of the dark red 2-quinoline derivative (**3p**) indicate similarity to compound (**3m-B**), the 4-quinoline congener (**3q**) is related to structure (**3o**) (methane C-H: δ_H 5.94 / δ_C 27.7 ppm). Again, only five different indene-C signals are observed due to rapid exchange. An independent proof of structure (**3q**) was achieved by X ray analysis (see below).

The less soluble, violet 3-pyridazine derivative (**3r**) has a central sp^2-C atom (δ 138.3 ppm; lack of an aliphatic C-H signal in the ^{1}H and ^{13}C nmr spectrum) and - according to the chemical shifts of the pyridazine system - a protonated diazine N atom, thus the species appears to be related to **3m-B** and **3p**. Fast equilibration again leads to only five different indene-C signals. In contrast, the 4-pyridazinyl congener (**3s**) is the only species of type (**3**) having the structure of the primary Michael addition product (in $CDCl_3$ solution). This follows from the occurence of an AM_2 spin system in the aliphatic region of the proton nmr spectrum and from the ^{13}C nmr data, which - in the indandione part of **3r** - closely resemble those of **1** (no

enolisation). The ^{13}C and ^{1}H nmr data of indandione (**1**), which are valuable for comparison purposes, are also given in the Experimental Part. The ^{13}C nmr assignments for **1** given in the literature[24] are obviously not correct, as we found a reverse order for the signals of C-4/7 and C-5/6 on basis of selective long-range INEPT experiments performed within this study.

Scheme 3



Crystal Structure of Compound (3q)•C_4H_8O (2-Butanone Solvate of 3q)

Red crystals suitable for X ray work turned out to be a 2-butanone solvate of **3q**. Technical details of the structure determination work are given in the experimental section. Atomic parameters are listed in Table 3. A view of the **3q** molecule in crystalline state is given in Figure 1. Compound **(3q)•C_4H_8O** can be considered as an inclusion compound in which the **3q** molecules form a host-lattice with channels extending at $x,z \sim 0,1/4$ and $x,z \sim 0,3/4$ parallel to y along the 2_1 screw axes of the monoclinic unit cell.

These channels are occupied by disordered 2-butanone solvent molecules as guests. It is likely that other solvent molecules may enter the channels upon crystallization and that the molar ratio between host **3q** and guest 2-butanone may deviate from 1:1.

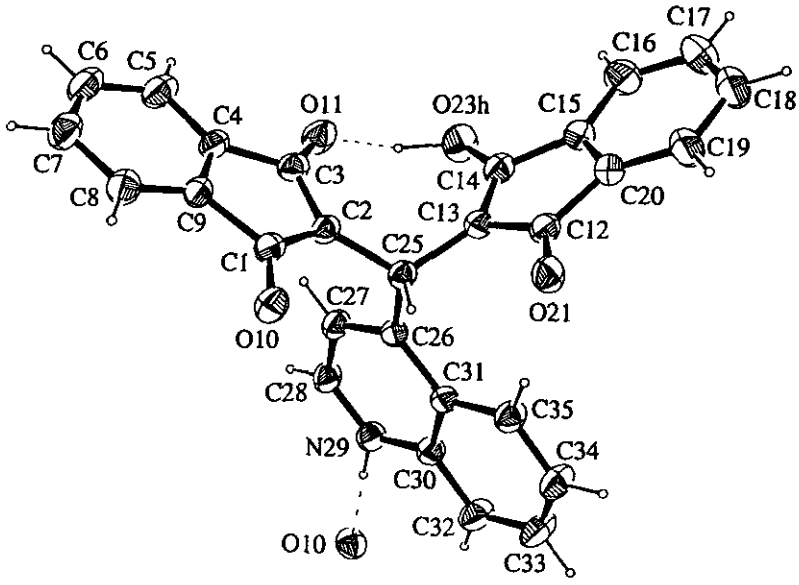


Figure 1. View of **3q** *in the crystal structure of* $\mathbf{3q \cdot C_4H_8O}$ *(Ortep plot, 30% ellipsoids, crystallographic numbering scheme).*

Selected bond lengths in Å (esd's ~ 0.004 Å): C(1)-C(9) = 1.495, C(3)-C(4) = 1.500, C(12)-C(20) = 1.490, C(14)-C(15) = 1.488, C(1)-C(2) = 1.412, C(3)-C(2) = 1.405, C(12)-C(13) = 1.457, C(14)-C(13) = 1.366, C(1)-O(10) = 1.254, C(3)-O(11) = 1.265, C(12)-O(21) = 1.228, C(14)-O(23h) = 1.314, C(2)-C(25) = 1.510, C(13)-C(25) = 1.512, C(26)-C(25) = 1.529, N(29)-C(28) = 1.319, N(29)-C(30) = 1.373. Mean aromatic C-C = 1.391. Hydrogen bonds: O(23h)...O(11) = 2.482, N(29)...O(10') = 2.635.

The **3q** molecule consists of two planar indene moieties with sp^2-hybridized bridgehead atoms C(2) and C(13) and a sp^3-hybridized hydrogen bearing central carbon C(25) which links the indene moieties with the quinoline residue (Figure 1). Formally there are two acid hydrogen atoms in the molecule. One of them, H(23), is bonded to O(23h) forming an extremely short and strong intramolecular hydrogen bond to O(11) as acceptor, O(23h)...O(11) = 2.482(3) Å. The second hydrogen atom, H(29n), is transferred to the quinolinium nitrogen N(29) and forms a short intermolecular hydrogen bond to O(10) of a

Table 3. Atomic coordinates and equivalent isotropic thermal displacement parameters for **3q•C_4H_8O**; H atoms omitted.

	x/a	*y/b*	*z/c*	U_{eq} [Å^2]
C(1)	0.4317(3)	0.5264(3)	0.39364(10)	0.044(1)
C(2)	0.5595(3)	0.5419(3)	0.39273(9)	0.042(1)
C(3)	0.6132(3)	0.6398(3)	0.43492(10)	0.048(1)
C(4)	0.5133(3)	0.6886(3)	0.46403(10)	0.047(1)
C(5)	0.5160(3)	0.7892(3)	0.50601(11)	0.063(1)
C(6)	0.4051(4)	0.8181(3)	0.52256(12)	0.071(1)
C(7)	0.2960(3)	0.7498(3)	0.49801(12)	0.066(1)
C(8)	0.2940(3)	0.6470(3)	0.45546(11)	0.057(1)
C(9)	0.4031(3)	0.6189(3)	0.43926(10)	0.046(1)
O(10)	0.3484(2)	0.4560(2)	0.36165(7)	0.0551(7)
O(11)	0.7232(2)	0.6900(2)	0.44795(7)	0.0622(8)
C(12)	0.7330(3)	0.2131(3)	0.36419(10)	0.045(1)
C(13)	0.7344(2)	0.3756(3)	0.37172(9)	0.041(9)
C(14)	0.8495(3)	0.4134(3)	0.40097(10)	0.049(1)
C(15)	0.9295(3)	0.2775(3)	0.41288(10)	0.050(1)
C(16)	1.0483(3)	0.2580(4)	0.44250(12)	0.068(1)
C(17)	1.0954(3)	0.1119(4)	0.44856(14)	0.080(1)
C(18)	1.0249(3)	-0.0094(4)	0.42613(14)	0.082(2)
C(19)	0.9034(3)	0.0111(3)	0.39707(13)	0.068(1)
C(20)	0.8579(3)	0.1544(3)	0.39075(11)	0.050(1)
O(21)	0.6452(2)	0.1371(2)	0.34025(8)	0.056(1)
O(23h)	0.8931(2)	0.5444(2)	0.42026(8)	0.067(1)
C(25)	0.6205(2)	0.4704(3)	0.35023(9)	0.041(1)
C(26)	0.6415(2)	0.5809(3)	0.30632(9)	0.040(1)
C(27)	0.6435(3)	0.7339(3)	0.31496(10)	0.047(1)
C(28)	0.6533(3)	0.8333(3)	0.27381(11)	0.050(1)
N(29)	0.6614(2)	0.7855(3)	0.22494(9)	0.049(1)
C(30)	0.6635(2)	0.6350(3)	0.21299(10)	0.045(1)
C(31)	0.6540(2)	0.5287(3)	0.25369(10)	0.041(1)
C(32)	0.6744(3)	0.5920(3)	0.16078(10)	0.060(1)
C(33)	0.6789(3)	0.4437(3)	0.14874(12)	0.069(1)
C(34)	0.6694(3)	0.3361(3)	0.18785(12)	0.062(1)
C(35)	0.6568(3)	0.3758(3)	0.23905(11)	0.052(1)
C(36s)	0.011(2)	0.222(6)	0.205(1)	0.59(4)
C(37s)	0.0082(8)	0.332(4)	0.270(1)	0.62(3)
C(38s)	0.056(2)	0.547(2)	0.2644(9)	0.26(1)
C(39s)	0.147(1)	0.559(1)	0.2453(4)	0.106(5)

C(36s) through C(39s) are peaks describing the disordered solvent molecule 2-butanone. Their refined site occupation factors are 0.95, 1.68, 0.70, and 0.51, respectively.

neighboring **3q** molecule, N(29)...O(10) = 2.635(3) Å. The compound is thus zwitterionic and conforms with the structural formula given in Scheme 3. The given proton distribution is well supported by the C – O bond lengths of the dioxyindane moieties: They are short for C(12) – O(21) [1.228(3) Å], intermediate for the hydrogen bond acceptors C(1) – O(10) and C(3) – O(11) [1.254(3) Å; 1.265(3) Å], and long for the hydrogen bond donating group C(14) – O(23h) [1.314(3) Å]. Likewise the C – N bonds of the quinolinium nitrogen N(29) are on average by about 0.02 Å longer than found in neutral quinolines. The outstanding shortness and strength of the hydrogen bond O(23h) – H(23)...O(11) cannot be overemphasized. It is by only 0.04 - 0.08 Å longer than the shortest known O – H...O hydrogen bonds present in diaquoxonium ions $H_5O_2^+$ and compares well in length to hydrogen bonds in acid salts of dicarboxylic acids, e.g. various hydrogen oxalates[25] (O...O = 2.457 - 2.593 Å) or potassium hydrogen tartrate[26] (O...O = 2.532 Å).

EXPERIMENTAL

Melting points were determined on a Reichert-Kofler hot-stage microscope and are uncorrected. The ir spectra (potassium bromide pellets) were recorded on a Jasco IRA-1 spectrophotometer or on a Perkin-Elmer FTIR 1605 spectrophotometer. Mass spectra were obtained either on a Hewlett-Packard 5890A/5970B-MSD (glc/ms) or on a Varian MAT 311A instrument (both EI, 70 eV). The nmr spectra were recorded on a Varian Unity*Plus* 300 spectrometer (299.95 MHz for ^{1}H, 75.43 MHz for ^{13}C) at 28°C, some selected ^{1}H nmr spectra were taken on a Bruker AC80 instrument (80.13 MHz). The solvent signal was used as an internal standard which was related to tetramethylsilane with δ 7.26 ppm (^{1}H in $CDCl_3$), δ 2.49 ppm (^{1}H in DMSO-d_6), δ 77.0 ppm (^{13}C in $CDCl_3$), and δ 39.5 ppm (^{13}C in DMSO-d_6). MO-Calculations were carried out on Sun SPARCstation 10-41 using the semiempirical AM1[18] and the SAM1-method[19] implemented in the AMPAC program package.[20] Column chromatographic separations were performed on Merck Kieselgel 60 (70-230 mesh). As not otherwise indicated all reagents used are commercially available, the yields given below are not optimized. Ethanol refers to the azeotrope with water.

1,3-Indandione (1*H*-Indene-1,3(2*H*)-dione) (**1**)

^{13}C nmr ($CDCl_3$): δ 197.0 (C-1,3), 143.3 (C-3a,7a), 135.4 (C-5,6), 123.0 (C-4,7), 44.9 (C-2); ^{13}C nmr (DMSO-d_6): δ 198.0 (C-1,3), 143.0 (C-3a,7a), 135.5 (C-5,6), 122.5 (C-4,7), 45.1 (C-2).

2-(1-Methyl-1*H*-pyrrol-2-ylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2a**)

A solution of 327 mg (3 mmol) of 1-methyl-2-pyrrolcarbaldehyde and 438 mg (3 mmol) of 1,3-indandione (**1**) in 10 ml of ethanol was heated to reflux for 20 h. After cooling, the precipitate was filtered off, washed with cold diisopropyl ether and recrystallized twice from ethyl acetate to afford 379 mg (53%) of orange needles, mp 186°C; ^1H nmr ($CDCl_3$): δ 8.62 (dd, $J_{3,4}$ = 4.4 Hz, $J_{3,5}$ = 1.5 Hz, 1H, pyrrole H-3), 7.94-7.89 (m, 2H, indene H-4,7), 7.72 (s, 1H, alkene-H),[27] 7.72-7.69 (m, 2H, indene H-5,6), 7.09 (m, 1H, pyrrole H-5), 6.41 (dd, $J_{3,4}$ = 4.4 Hz, $J_{4,5}$ = 2.4 Hz, 1H, pyrrole H-4), 3.89 (s, 3H, NCH_3); ir (KBr): cm^{-1} 1710 (C=O), 1665 (C=O); ms: m/z (%) 237 (M^+, 100), 236 (22), 220 (31), 208 (13), 192 (10), 181 (15), 180 (30), 152 (12), 139 (12), 105 (34), 104 (18), 77 (14), 76 (13). *Anal.* Calcd for $C_{15}H_{11}NO_2$: C, 75.94; H, 4.67; N, 5.90. Found: C, 75.71; H, 4.43; N, 5.84.

2-(2-Furanylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2b**)

Compound (**2b**) was prepared according to ref.;[10] ^1H nmr ($CDCl_3$): δ 8.57 (d, $J_{3,4}$ = 3.6 Hz, 1H, furan H-3), 7.97-7.94 (m, 2H, indene H-4,7), 7.78-7.73 (m, 3H, indene H-5,6 and furan H-5), 7.73 (s, 1H, alkene-H), 6.71 (dd, $J_{3,4}$ = 3.6 Hz, $J_{4,5}$ = 1.8 Hz, 1H, furan H-4); ir (KBr): cm^{-1} 1715 (C=O), 1670 (C=O); ms: m/z (%) 224 (M^+, 100), 223 (29), 196 (24), 168 (26), 140 (16), 139 (30), 76 (13).

2-(2-Thienylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2c**)

Compound (**2c**) was prepared according to ref.; [11] ^1H nmr ($CDCl_3$): δ 8.05 (dd, $J_{3,4}$ = 3.9 Hz, $J_{3,5}$ = 1.2 Hz, 1H, thiophene H-3), 7.99 (s, 1H, alkene-H), 7.98-7.95 (m, 2H, indene H-4,7), 7.85 (dd, $J_{4,5}$ = 4.9 Hz, $J_{3,5}$ = 1.2 Hz, 1H, thiophene H-5), 7.78-7.75 (m, 2H, indene H-5,6), 7.22 (dd, $J_{3,4}$ = 3.9 Hz, $J_{4,5}$ = 4.9 Hz, 1H, thiophene H-4); ir (KBr): cm^{-1} 1710 (C=O), 1665 (C=O); ms: m/z (%) 240 (M^+, 100), 239 (78), 212 (13), 184 (22), 152 (13), 139 (11), 104 (13), 76 (13).

2-(5-Methyl-2-thienylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2d**)

A solution of 3.450 g (27.34 mmol) of 5-methylthiophene-2-carbaldehyde and 3.996 g (27.34 mmol) of **1** in 70 ml of ethanol was treated with ten drops of piperidine and heated to reflux for 1.5 h. After cooling, the precipitate was filtered off and purified by column chromatography (eluent: dichloromethane - ethyl acetate, 3:1) followed by recrystallization from ethanol - ethyl acetate to afford 1.000 g (14%) of yellow crystals, mp 133-135°C; ^{1}H nmr ($CDCl_3$): δ 8.02-7.69 (m, 6H, indene H-4,5,6,7, alkene-H, thiophene H-3), 6.93 (d, $J_{3,4}$ = 3.6 Hz, 1H, thiophene H-4), 2.63 (s, 3H, CH_3); ir (KBr): cm^{-1} 1715 (C=O), 1665 (C=O); ms: m/z (%) 255 (21), 254 (M^+, 100), 253 (50), 239 (34), 197 (24), 165 (14), 76 (15). *Anal.* Calcd for $C_{15}H_{10}O_2S$: C, 70.85; H, 3.96. Found: C, 70.75; H, 4.02.

2-(5-Nitro-2-thienylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2e**)

A solution of 3.000 g (19.09 mmol) of 5-nitrothiophene-2-carbaldehyde, 2.790 g (19.09 mmol) of **1** and two drops of piperidine in 60 ml of ethanol was heated to reflux for 1.5 h. After cooling, the precipitate was filtered off and washed with cold ethanol to afford 5.010 g (92%) of yellow crystals, mp 298°C; ^{1}H nmr (DMSO-d_6): 8.20-8.12 (m, 3H, thiophene H-3, thiophene H-4, alkene-H), 8.00 (m, 4H, indene H-4,5,6,7); ir (KBr): cm^{-1} 1715 (C=O), 1665 (C=O); ms: m/z (%) 285 (M^+, 74), 240 (16), 239 (100), 183 (19), 139 (46), 76 (16). *Anal.* Calcd for $C_{14}H_7NO_4S$: C, 58.95; H, 2.47; N, 4.91. Found: C, 58.67; H, 2.62; N, 4.69.

2-(5-Bromo-2-thienylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2f**)

Compound (**2f**) was prepared from 2.500 g (13.09 mmol) of 5-bromothiophene-2-carbaldehyde, 1.921 g (13.09 mmol) of **1** (in 50 ml of ethanol plus 2 drops of piperidine) as described for the preparation of **2e**. Yield: 3.340 g (80%) of yellow crystals, mp 207°C; ^{1}H nmr ($CDCl_3$): δ 8.04-7.62 (m, 6H, indene H-4,5,6,7, alkene-H, thiophene H-3), 7.21 (d, $J_{3,4}$ = 4.1 Hz, thiophene H-4); ir (KBr): cm^{-1} 1715 (C=O), 1670 (C=O); ms: m/z (%) 318/320 (M^+, 46/48), 240 (23), 239 (100), 183 (16), 139 (37), 119 (14), 76 (19). *Anal.* Calcd for $C_{14}H_7O_2BrS$: C, 52.68; H, 2.21. Found: C, 52.38; H, 2.31.

2-(3-Thienylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2g**)

A solution of 2.000 g (17.83 mmol) of 3-thiophenecarbaldehyde and 2.606 g (17.83 mmol) of **1** in 50 ml of ethanol containing 2 drops of piperidine was heated to reflux for 1.5 h. After cooling, the precipitate was filtered off and recrystallized from ethanol to afford 2.540 g (59%) of yellow crystals, mp 158°C; ^{1}H nmr ($CDCl_3$): δ 8.94 (dd, $J_{2,5}$ = 3.0 Hz, $J_{2,4}$ = 0.9 Hz, 1H, thiophene H-2), 8.03 (dd, $J_{4,5}$ = 5.0 Hz, $J_{2,4}$ = 0.9 Hz, 1H, thiophene H-4), 7.97-7.94 (m, 2H, indene H-4,7), 7.84 (s, 1H, alkene-H), 7.78-7.75 (m, 2H, indene H-5,6), 7.38 (dd, $J_{4,5}$ = 5.0 Hz, $J_{2,5}$ = 3.0 Hz, 1H, thiophene H-5); ir (KBr): cm^{-1} 1720 (C=O), 1680 (C=O); ms: m/z (%) 240 (M^+, 100), 239 (92), 212 (10), 184 (22), 139 (14), 104 (11), 76 (19). *Anal.* Calcd for $C_{14}H_8O_2S$: C, 69.98; H, 3.36. Found: C, 70.11; H; 3.48.

2-(2*H*-Pyrazol-3-ylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2h**)

Compound (**2h**) was prepared from 3.000 g (31.22 mmol) 3-pyrazolecarbaldehyde and 4.663 g (31.22 mmol) of **1** in 70 ml of ethanol according to the procedure given for the preparation of **2g**. Recrystallization from ethanol afforded 4.760 g (68%) of yellow crystals, mp 207-211°C; ^{1}H nmr ($CDCl_3$): δ 13.92 (broad s, 1H, NH), 8.10-8.06 (m, 1H, indene H-7), 8.04-8.00 (m, 1H, indene H-4), 7.89-7.83 (m, 2H, indene H-5,6), 7.77 (m, 2H, alkene-H, pyrazole H-5(3)), 6.89 (d, $J_{3,4}$ = 1.9 Hz, 1H, pyrazole H-4); ir (KBr): cm^{-1} 3190 (N-H), 1715 (C=O), 1665 (C=O); ms: m/z (%) 224 (M^+, 100), 197 (12), 196 (12), 170 (19), 168 (19), 140 (29), 139 (42), 114 (14), 76 (24), 63 (12), 50 (11). *Anal.* Calcd for $C_{13}H_8N_2O_2$: C, 69.64; H, 3.60; N, 12.49. Found: C, 69.34; H, 3.80; N, 12.32.

2-(1-Benzyl-1*H*-pyrazol-4-ylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2i**)

Compound (**2i**) was prepared from 200 mg (1.07 mmol) of 1-benzylpyrazol-4-carbaldehyde[28] and 157 mg (1.07 mmol) of **1** in 5 ml of ethanol (1 drop of piperidine as catalyst) according to the procedure given for the preparation of **2g**. Recrystallization from methanol - acetone yielded 120 mg (36%) of yellow crystals, mp 204°C; ^{1}H nmr ($CDCl_3$): δ 9.06 (s, 1H, pyrazole H-5), 8.20 (s, 1H, pyrazole H-3), 7.95-7.91 (m, 2H, indene H-4,7), 7.77-7.73 (m, 2H, indene H-5,6), 7.76 (s, 1H, alkene-H), 7.39-7.32 (m, 5H, Ph-H), 5.40 (s, 2H, CH_2); ir (KBr): cm^{-1} 1710 (C=O), 1675 (C=O); ms: m/z (%) 315 (13), 314 (M^+, 61), 313 (23), 91 (100), 65 (19). *Anal.* Calcd for $C_{20}H_{14}N_2O_2$: C, 76.42; H, 4.49; N, 8.91. Found: C, 76.49; H, 4.32; N, 8.58.

2-(1*H*-Imidazol-2-ylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2j**)

Compound (**2j**) was prepared from 800 mg (8.33 mmol) of 2-imidazolecarbaldehyde and 1.217 g (8.33 mmol) of **1** in 20 ml of ethanol (1 drop of piperidine as catalyst) according to the procedure given for the preparation of **2g**. Recrystallization from methanol gave 574 mg (31%) of yellow crystals of mp 208°C; ^{1}H nmr ($CDCl_3$): δ 13.81 (br s, 1H, NH), 7.99-7.92 (m, 2H, indene H-4,7), 7.88 (s, 1H, alkene-H), 7.83-7.75 (m, 2H, indene H-5,6), 7.54 (s, 1H, imidazole H-4), 7.40 (d, J = 2.0 Hz, 1H, imidazole H-5); ir (KBr): cm^{-1} 1710 (C=O), 1660 (C=O); ms: m/z (%) 224 (M^+, 88), 169 (14), 168 (100), 141 (28), 140 (12), 114 (30), 113 (16), 76 (17). *Anal.* Calcd for $C_{13}H_8N_2O_2$: C, 69.64; H, 3.60; N, 12.49. Found: C, 69.44; N, 3.89; N 12.11.

2-(1*H*-Indol-3-ylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2k**)

A solution of 290 mg (2 mmol) of 3-indolecarbaldehyde and 292 mg (2 mmol) of **1** in 20 ml of dry ethanol was stirred for 20 h at room temperature. After cooling (4°C), the precipitate was filtered off and washed with cold ethanol to afford 390 mg (71%) of orange crystals, mp 310°C (lit., [12] mp 308°C); ^{1}H nmr ($CDCl_3$): δ 9.77 (d, J = 3.3 Hz, indole H-2), 9.01 (br s, 1H, NH), 8.35 (s, 1H, alkene-H), 8.04 (m, 1H, indole H-4), 7.99-7.94 (m, 2H, indene H-4,7), 7.77-7.74 (m, 2H, indene H-5,6), 7.50 (m, 1H, indole H-7), 7.40-7.33 (m, 2H, indole H-5,6); ir (KBr): cm^{-1} 3240 (N-H), 1712 (C=O), 1659 (C=O).

2-(4-Oxo-4*H*-[1]benzopyran-3-ylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2l**)

Compound (**2l**) was prepared from 174 mg (1 mmol) of 3-chromonecarbaldehyde and 146 mg (1 mmol) of **1** according to the procedure given for the preparation of **2k**. Recrystallization from DMF afforded 165 mg (61%) of yellow crystals, mp 270-273°C (lit.,[13] mp 272-274°C); ^{1}H nmr ($CDCl_3$): δ 10.39 (d, J = 0.6 Hz, 1H, chromone H-2), 8.44 (d, J = 0.6 Hz, alkene-H), 8.33 (m, 1H, chromone H-5), 8.05-8.00 (m, 2H, indene H-4,7), 7.86-7.81 (m, 2H, indene H-5,6), 7.76 (m, 1H, chromone H-7), 7.57 (m, 1H, chromone H-8), 7.48 (m, 1H, chromone H-6); ir (KBr): cm^{-1} 1732 (C=O), 1692 (C=O), 1637 (C=O).

2-(3-Pyridinylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2n**)

Compound (**2n**) was prepared according to ref.;[6] ^{1}H nmr ($CDCl_3$): δ 9.13 (m, 1H, pyridine H-2), 9.09 (m,

1H, pyridine H-4), 8.67 (m, 1H, pyridine H-6), 7.97-7.94 (m, 2H, indene H-4,7), 7.80-7.75 (m, 2H, indene H-5,6), 7.78 (s, 1H, alkene-H), 7.41 (m, 1H, pyridine H-5).

2-(4-Pyridinylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2o**)

Compound (**2o**) was prepared according to ref.;[6,14] ^{1}H nmr (DMSO-d_6): δ 8.77 (m, 2H, pyridine H-2,6), 8.17 (m, 2H, pyridine H-3,5), 8.05-7.95 (m, 4H, indane H-4,5,6,7), 7.79 (s, 1H, alkene-H).

2-(4-Pyridazinylmethylene)-1*H*-indene-1,3(2*H*)-dione (**2s**)

Compound (**2s**) was prepared according to ref.;[9] ^{1}H nmr ($CDCl_3$): δ 9.65 (dd, $J_{3,5}$ = 2.5 Hz, $J_{3,6}$ = 1.0 Hz, 1H, pyridazine H-3), 9.41 (dd, $J_{5,6}$ = 5.4 Hz, $J_{3,6}$ = 1.0 Hz, pyridazine H-6), 8.60 (dd, $J_{3,5}$ = 2.5 Hz, $J_{5,6}$ = 5.4 Hz, 1H, pyridazine H-5), 8.09-8.04 (m, 2H, indene H-4,7), 7.92-7.88 (m, 2H, indene H-5,6), 7.72 (s, 1H, alkene-H).

Reaction of **1** with 2-Pyridinecarbaldehyde in Ethanol (Compound **3m-A**)

A solution of 2-pyridinecarbaldehyde (1.07 g, 10 mmol) and 1.46 g (10 mmol) of **1** in 30 ml of ethanol was stirred for 2 h at room temperature. Then the precipitate was filtered off from the red solution and washed several times with cold diisopropyl ether to give 1.26 g (66% regarding **1**) of **3m-A** as a yellow powder of mp 161-163°C. Upon recrystallization from ethanol-isopropanol (1:1) the material partly changed to isomer (**3m-B**). Compound (**3m-A**) had ^{1}H nmr (DMSO-d_6, 80 MHz): δ 8.29 (m, 1H, pyridine H-6), 7.55 (m, 1H, pyridine H-4), 7.33-6.95 (m, 11H, 10H after addition of D_2O, pyridine H-3, pyridine H-5, indene-H, OH), 5.17 (s, 1H, methane-H); ir (KBr): cm^{-1} 3422 (OH), 1719 (C=O); ms: m/z (%) 381 (M^+, 1), 236 (46), 235 (100), 207 (23), 180 (12), 179 (58), 178 (28), 146 (93), 118 (20), 105 (16), 104 (77), 101 (13), 90 (34), 89 (17), 77 (14), 76 (91), 75 (28), 74 (18), 63 (15), 51 (20), 50 (47). *Anal.* Calcd for $C_{24}H_{15}NO_4$: C, 75.58; H, 3.96; N, 3.67. Found: C, 75.66, H, 4.03; N, 3.65.

Reaction of **1** with 2-Pyridinecarbaldehyde in Dichloromethane (Compound **3m-B**)

A degassed (bubbling Ar) solution of 2-pyridinecarbaldehyde (535 mg, 5 mmol) and **1** (730 mg, 5 mmol) in 10 ml of CH_2Cl_2 was stored for 50 h in the refrigerator (4°C) under Ar. The red precipitate was filtered off and washed with cold diisopropyl ether to afford 502 mg (53%) of a red powder. After preparative tlc

(eluent: ethyl acetate - methanol, 5:1) 233 mg (25% regarding **1**) of a deep-red powder of mp 270-272°C (decomp.) were obtained; ^{1}H nmr (DMSO-d_6, 80 MHz): δ 8.83 (m, 1H, pyridine H-6), 8.44 (m, 1H, pyridine H-4), 8.14-8.09 (m, 2H, pyridine H-3, pyridine H-5), 7.73-7.49 (m, 8H, indene-H); ir (KBr): cm^{-1} 3434 (OH), 1716 (C=O), 1646; ms: m/z (%) 381 (M^+, 3), 380 (23), 379 (92), 335 (15), 334 (42), 323 (18), 322 (57), 309 (40), 278 (41), 95 (13), 87 (37), 86 (61), 78 (29), 51 (19), 49 (100). *Anal.* Calcd for $C_{24}H_{15}NO_4$: C, 75.58; H, 3.96; N, 3.67. Found: C, 75.77; H, 3.67; N, 3.67.

Reaction of **1** with 4-Pyridinecarbaldehyde in Dichloromethane (Compound **3o**)

A solution of 4-pyridinecarbaldehyde (107 mg, 1 mmol) and 146 mg (1 mmol) of **1** in 5 ml of CH_2Cl_2 was treated with a catalytic amount of piperidine and stirred for 4 h at room temperature. After storing the mixture at -20°C overnight, the precipitate was filtered off and recrystallized from methanol to afford 120 mg (63% regarding **1**) of nearly colorless crystals of mp 184-186°C; ^{1}H nmr (DMSO-d_6): δ 14.0-10.0 (br, exchangeable with D_2O, 1H), 8.65 (AA', $J_{2,3}$ = 6.7 Hz, 2H, pyridine H-2,6), 7.75 (XX', $J_{2,3}$ = 6.7 Hz, 2H, pyridine H-3,5), 7.35-7.31 (m, 4H, indene H-5,6), 7.28-7.23 (m, 4H, indene H-4,7), 5.25 (s, 1H, methane-H); ^{13}C nmr (DMSO-d_6): δ 187.1 (indene C-1,3), 164.7 (pyridine C-4), 141.9 (pyridine C-2,6), 137.8 (indene C-3a,7a), 130.7 (indene C-5,6), 124.7 (pyridine C-3,5), 118.6 (indene C-4,7), 106.1 (indene C-2), 30.5 (methane C-H, ^1J = 125.0 Hz); ir (KBr): cm^{-1} 1735 (C=O), 1690 (C=O); ms: m/z (%) 381 (M^+, 0.4), 236 (12), 235 (77), 234 (47), 179 (15), 178 (11), 152 (10), 146 (40), 118 (14), 104 (64), 101 (10), 90 (27), 89 (13), 77 (17), 76 (100), 75 (37), 74 (34), 63 (21), 62 (11), 51 (36), 50 (79), 42 (14), 39 (14). *Anal.* Calcd for $C_{24}H_{15}NO_4$: C, 75.58; H, 3.96; N, 3.67. Found: C, 75.41; H, 4.09; N, 3.55.

Reaction of **1** with 2-Quinolinecarbaldehyde in Ethanol (Compound **3p**)

A solution of 2-quinolinecarbaldehyde (157 mg, 1 mmol) and **1** (146 mg, 1 mmol) in 5 ml of dry ethanol was stirred for 24 h. After cooling, the dark red precipitate was filtered off and washed with cold diisopropyl ether to afford 55 mg of **3p** as a red powder. The filtrate was evaporated to dryness and the residue was subjected to column chromatography (eluent: ethyl acetate - methanol, 9:1) to afford another 119 mg of **3p**. Overall yield: 174 mg (80% regarding **1**) of a red powder, mp ~312°C (decomp.); ^{1}H nmr (DMSO-d_6): δ 9.03 (d, $J_{3,4}$ = 8.7 Hz, 1H, quinoline H-4), 8.42 (d, $J_{7,8}$ = 7.7 Hz, 1H, quinoline H-8), 8.22 (d, $J_{5,6}$ = 8.4 Hz, 1H, quinoline H-5), 8.13 (t, 1H, quinoline H-7), 8.09 (d, $J_{3,4}$ = 8.7 Hz, 1H, quinoline

H-3), 7.99 (t, 1H, quinoline H-6), 7.67-7.62 (m, 4H, indene H-5,6), 7.59-7.54 (m, 4H, indene H-4,7); ir (KBr): cm^{-1} 1658, 1625; ms: m/z (%) 431 (M^+, 6), 430 (32), 429 (100), 215 (11), 158 (12), 104 (10), 76 (13), 44 (10). *Anal.* Calcd for $C_{28}H_{17}NO_4$: C, 77.95; H, 3.97; N, 3.25. Found: C, 77.88; H, 3.60; N, 3.06.

Reaction of **1** with 4-Quinolinecarbaldehyde in Dichloromethane (Compound **3q**)

To a solution of 157 mg (1 mmol) of 4-quinolinecarbaldehyde in 5 ml of dichloromethane was added 146 mg (1 mmol) of **1** and the mixture was stirred for 20 h at ambient temperature. The orange precipitate was then filtered off, washed with cold dichloromethane and recrystallized from acetone to afford 102 mg (48%) of orange-red prisms, mp 147-149°C. Crystals of suitable size for X ray analyis were obtained by crystallization from 2-butanone. Compound (**3q**) had ^1H nmr (DMSO-d_6): δ 9.09 (d, $J_{2,3}$ = 6.0 Hz, 1H, quinoline H-2), 8.92 (d, $J_{7,8}$ = 8.4 Hz, 1H, quinoline H-8), 8.12 (m, 1H, quinoline H-7), 8.07 (m, 1H, quinoline H-3), 7.99 (m, 1H, quinoline H-5), 7.90 (m, 1H, quinoline H-6), 7.34-7.30 (m, 4H, indene H-5,6), 7.26-7.22 (m, 4H, indene H-4,7), 5.94 (s, 1H, methane-H); ^{13}C nmr (DMSO-d_6): δ 187.4 (indene C-1,3), 160.4 (quinoline C-4), 144.9 (quinoline C-2), 139.0 (quinoline C-8a), 137.7 (indene C-3a,7a), 132.9 (quinoline C-5), 130.7 (indene C-5,6), 128.5 (quinoline C-6), 126.2 (quinoline C-4a), 125.3 (quinoline C-8), 122.3 (quinoline C-7), 119.8 (quinoline C-3), 118.6 (indene C-4,7), 105.0 (broad, indene C-2), 27.7 (methane C-H); ir (KBr): cm^{-1} 3437 (O-H, N-H), 2500 (OH), 1712 (C=O), 1667 (C=O); ms: m/z (%) 287 (11), 286 (21), 285 (100), 284 (18), 257 (18), 256 (39), 240 (11), 230 (10), 229 (29), 228 (43), 227 (16), 202 (16), 201 (32), 200 (31), 170 (11), 152 (10), 146 (62), 118 (14), 115 (13), 114 (14), 105 (19), 104 (68), 101 (14), 100 (20), 90 (24), 89 (15), 87 (12), 77 (22), 76 (89), 75 (22), 74 (17), 63 (15), 57 (12), 51 (16), 50 (36), 49 (18), 44 (10). *Anal.* Calcd for $C_{28}H_{17}NO_4$: C, 77.95; H, 3.97; N, 3.25. Found: C, 77.68; H, 4.14; N, 3.26.

Reaction of **1** and 3-Pyridazinecarbaldehyde (Compound **3r**)

A solution of 3-pyridazinecarbaldehyde (108 mg, 1 mmol) and **1** (146 mg, 1 mmol) in 5 ml of methanol containing a catalytic amount of piperidine was heated to reflux for 1.5 h. After cooling, the precipitate was filtered off and recrystallized from ethanol to afford 120 mg (62% regarding **1**) of an intensively red-violet powder, mp 281-282°C; ^1H nmr (DMSO-d_6): δ 10.30 (br s, exchangeable with D_2O, 1H, OH or NH), 9.56 (dd, $J_{5,6}$ = 5.1 Hz, $J_{4,6}$ = 1.6 Hz, 1H, pyridazine H-6), 8.55 (dd, $J_{4,5}$ = 8.5 Hz, $J_{4,6}$ = 1.6 Hz, 1H,

pyridazine H-4), 8.38 (dd, $J_{5,6}$ = 5.1 Hz, $J_{4,5}$ = 8.5 Hz, 1H, pyridazine H-5), 7.67-7.62 (m, 4H, indene H-5,6), 7.59-7.55 (m, 4H, indene H-4,7), 8.20-7.00 (br s, exchangeable with D_2O, 2H, OH, NH); ^{13}C nmr (DMSO-d_6): δ 187.8 (indene C-1,3), 161.6 (pyridazine C-3), 151.0 (pyridazine C-6), 140.4 (indene C-3a,7a), 138.3 (alkene-C), 136.0 (pyridazine C-4), 132.9 (indene C-5,6), 132.8 (pyridazine C-5), 120.7 (indene C-4,7), 115.1 (indene C-2); ir (KBr): cm^{-1} 1740 (C=O), 1700 (C=O), 1660 (C=O); ms: m/z (%) 382 (M^+, 2), 381 (12), 380 (49), 337 (26), 336 (100), 335 (11), 324 (12), 323 (45), 307 (20), 280 (17), 279 (29), 239 (13), 213 (11), 163 (10), 146 (10), 137 (11), 105 (10), 104 (30), 77 (15), 76 (47), 75 (11), 52 (22), 51 (23), 44 (49), 43 (17), 39 (11), 36 (12). *Anal.* Calcd for $C_{23}H_{14}N_2O_4$: C, 72.24; H, 3.69; N, 7.33. Found: 72.10; H, 3.37; N, 7.04.

2,2'-(4-Pyridazinylmethylene)bis(1*H*-indene-1,3(2*H*)-dione) (**3s**)

Compound (**3s**) was prepared according to ref.;[9] ^{13}C nmr ($CDCl_3$): δ 197.9 and 197.0 (indene C-1,C-3), 152.3 (pyridazine C-3), 150.9 (pyridazine C-6), 141.7 and 141.6 (indene C-3a,7a), 139.0 (pyridazine C-4), 136.1 and 136.0 (indene C-5,C-6), 126.5 (pyridazine C-5), 123.5 (indene C-4,C-7), 53.4 (indene C-2), 38.4 (methane C-H).

X-Ray Structure Determination of Compound **3q**•C_4H_8O (2-Butanone Solvate of **3q**)[29]

Compound $C_{28}H_{17}NO_4$•C_4H_8O = $C_{32}H_{25}NO_5$, M_r = 503.53, monoclinic, $P2_1/c$, a = 10.965(3) Å, b = 8.891(2) Å, c = 25.118(6) Å, β = 101.74(2)°, V = 2397.5(10) Å^3, Z = 4, D_c = 1.395 g cm^{-3}, μ = 0.094 mm^{-1}, $F(000)$ = 1056, T = 24 °C. A red crystal (0.1 x 0.2 x 0.4 mm) was used for data collection (Philips PW1100 diffractometer, Mo Kα radiation, λ = 0.71069 Å). Of 5165 reflections collected (Θ-2Θ scans, Θ_{max} = 24°, correction for *LP*, absorption neglected), 3769 were independent and all were used for solving the structure with direct methods (program XTAL3.2)[30] and subsequent least-squares refinement on F^2 (program SHELXL93).[31] All non-hydrogen atoms were refined anisotropically. The solvent molecule 2-butanone was found to reside severely disordered in channels. Its diffuse electron density ditribution could not be interpreted in terms of a discrete molecule but could be satisfactorily described by four carbon atoms which were refined in *x*, *y*, *z*, U_{ij} and *site occupation factors*. The hydrogen atoms of the host molecule **3q** were located from a difference Fourier synthesis and were refined either without constraints [O(23h) and N(29) bonded H atoms] or were inserted in idealized positions and refined riding

with the C atoms to which they were bonded. Final $R1 = \Sigma||F_o|-|F_c||/\Sigma|F_o| = 0.106$, $wR2 = [(w(F_o^2-F_c^2)^2)/(w(F_o^2)^2)]^{1/2} = 0.123$ and $S = 0.95$ for all data and 346 parameters; $R1 = 0.048$ for the 2222 reflections with $F_o>4\sigma(F_o)$; final difference Fourier map showed minimum and maximum values of -0.20 and +0.26 e $Å^{-3}$.

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