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Reaction of 3-phenyl-3-aminoquinoline-2,4-diones with isothiocyanates. Facile access to novel spiro-linked 2-thioxoimidazolidine-oxindoles and imidazoline-2-thiones

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ABSTRACT

3-Phenyl-3-amino-1*H*,3*H*-quinoline-2,4-diones (**1**) react with alkyl or aryl isothiocyanates to give novel 9b-hydroxy-3a-phenyl-1,2,3,3a-tetrahydro-2-thioxo-5*H*-imidazo[4,5-*c*]quinolin-4(9b*H*)-ones in high yields. These compounds rearrange in boiling acetic acid or concentrated hydrochloric acid to give novel 5-phenyl-2-thioxospiro[4*H*-imidazol-4,3′-[3*H*]indol]-2′(1′*H*,3*H*)-ones, 5-hydroxy-5-phenyl-2-thioxospiro[imidazolidine-4,3′-[3*H*]indol]-2′-ones and (2-methylaminophenyl)-5-phenyl-1*H*-imidazole-2(3*H*)-thiones. All compounds were characterized by their ^{1}H, ^{13}C, IR and MS data, and in some cases also by ^{15}N NMR data. The structures and compositions of four compounds were confirmed by single crystal X-ray diffraction.

1. Introduction

In our laboratory, much attention has been paid to the reactivity of 3-alkyl/aryl-3-amino-1*H*,3*H*-quinoline-2,4-diones.[1] The addition of these compounds to isocyanic acid (from the decomposition of urea or nitrourea) or isocyanates yields products that rearrange in an acidic media to give—depending on the character of the substituents—imidazoquinazolines, oxindoles, indolylureas, bis[2-(imidazolyl)phenyl]ureas, imidazolones and spiro-linked imidazolidine-oxindoles. These transformations, which were briefly illustrated in our last paper on this topic,[1] provide simple preparative methods for new types of heterocyclic compounds.

The exceptional structural diversity obtained from the molecular rearrangement mentioned above prompted us to examine the analogous addition of 3-aminoquinolinediones to isothiocyanates, as well as the acid-catalyzed rearrangement of the resulting products. We anticipated the formation of new sulfur-containing heterocycles; such compounds are of interest since many biologically active compounds belong to this structural class.[2,3]

Previous work has demonstrated that adducts of 3-aminoquinolinediones and isocyanates undergo rearrangements that largely depend on the substituents present at positions 1 and 3 of the starting compounds.[1] Consequently, we divided the starting 3-aminoquinolinediones into three different groups.[4] Compounds of the first group, containing compounds substituted at position 1 with an alkyl or aryl group and at position 3 with an alkyl group, react with alkyl or aryl isothiocyanates to give cyclic adducts, which rearrange under acidic conditions to (*E*)- and/or (*Z*)-4-butylidene-2-thioxo-1*H*′-spiro[imidazoline-5,3′-indole]-2,2′-diones.[4] In our last paper on this subject we studied compounds of the second group, which lack a substituent at position 1.[5] These react with methyl and phenyl isothiocyanates to yield analogous cyclic addition products; however, these rearrange in acidic media to three different products: 4-(2-aminophenyl)-1*H*-imidazole-2(3*H*)-thiones, 1,3-bis(2-(2,3-dihydro-2-thioxo-1*H*-imidazol-5-yl)phenyl)ureas and (as minor products) *N*-(2-(2,3-dihydro-2-thioxo-1*H*-imidazol-4-yl)phenyl)acetamides.

In this work, we demonstrate that the reaction of 3-aminoquinolinediones of the third group, bearing an alkyl or aryl group in position 1 and a phenyl group at position 3 (**1**), provides cyclic addition product **3**, which rearrange in an acidic medium to give novel 5-phenyl-2-thioxospiro[4*H*-imidazol-4,3′-[3*H*]indol]-2′(1′*H*,3*H*)-ones

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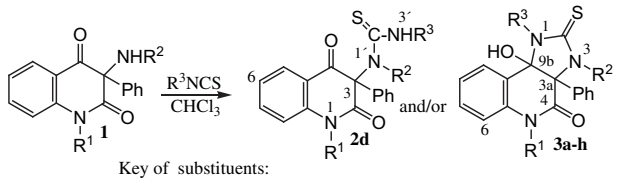


	a	b	c	d	e	f	g	h
R^1	Me	Me	Ph	Ph	Me	Me	Ph	Ph
R^2	H	H	H	H	Bu	Bu	Bu	Bu
R^3	Me	Ph	Me	Ph	Me	Ph	Me	Ph

Scheme 1.

Table 1
Preparation of compounds **2** and **3** by the reaction of 3-aminoquinolinediones **1** with isothiocyanates

Entry	Starting compound	Substituents[a]			Time (h)	Products (yield, %)
		R^1	R^2	R^3		
1	**1a**	Me	H	Me	3	**3a** (73)
2	**1a**	Me	H	Ph	3	**3b** (77)
3	**1c**	Ph	H	Me	3	**3c** (86)
4	**1c**	Ph	H	Ph	2	**2d** (48), **3d** (35)
5	**1e**	Me	Bu	Me	4	**3e** (66)
6	**1e**	Me	Bu	Ph	10	**3f** (74)
7	**1g**	Ph	Bu	Me	1	**3g** (90)
8	**1g**	Ph	Bu	Ph	2	**3h** (88)

[a] R^3 from isothiocyanate.

4, 5-hydroxy-5-phenyl-2-thioxospiro[imidazolidine-4,3′-[3*H*]indol]-2′-ones **5** and (2-methylaminophenyl)-5-phenyl-1*H*-imidazole-2(3*H*)-thiones **6**.

2. Results and discussion

Isothiocyanates were reacted with 3-amino-3-phenylquinolinediones **1** by boiling the reaction components in chloroform (Scheme 1, Table 1). Methyl isothiocyanate and phenyl isothiocyanate were chosen as model thiocyanates; methyl and phenyl groups were similarly chosen as substituents for position 1. The starting amines **1** (Scheme 1) were obtained from the corresponding 3-chloro derivatives according to procedures described elsewhere.[6] One novel amine **1c** was prepared.

In principle, 3-aminoquinolinediones may afford two different adducts in the reaction with isothiocyanates: 3-thioureido-1*H*,3*H*-quinoline-2,4-diones and/or cyclic 9b-hydroxy-1,2,3,3a-tetrahydro-2-thioxo-5*H*-imidazo[4,5-*c*]quinolin-4(9b*H*)-ones. In the reaction of 3-aminoquinolinediones with isocyanates,[1] both acyclic and cyclic products were obtained. However, in previous work,[4,5] the reaction of 3-aminoquinolinediones with isothiocyanates was find to provide, with only one exception, the cyclic products. Our present findings appear to confirm this trend; the selected 3-amino-3-phenylquinoline-2,4-diones **1** react with isothiocyanates to give only the cyclic isomers **3** in good to very good yields (Scheme 1, Table 1). NMR spectra of compounds **3** are given in Table 2. Characteristic hydroxyl proton signals appear in the ^{1}H NMR spectra in the region of 6.80–7.63 ppm. Additionally, ^{13}C signals arising from the sp^3 hybridized carbon atoms at position 3a lie in the region of 72.0–

Table 2
^{1}H and ^{13}C chemical shifts (δ, ppm) of compounds **3a**–**h** in DMSO-d_6

Position	**3a**		**3b**		**3c**		**3d**		**3e**		**3f**		**3g**		**3h**	
	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C
2	—	183.6	—	183.4	—	183.7	—	183.6	—	184.7	—	184.2	—	184.8	—	184.3
3a	—	72.0	—	73.0	—	72.4	—	73.6	—	77.5	—	78.6	—	78.0	—	79.0
4	—	168.4	—	168.5	—	169.6	—	168.7	—	168.1	—	168.1	—	138.3	—	158.3
5a	—	137.3	—	137.3	—	138.4	—	[a]	—	137.0	—	137.0	—	138.0	—	[b]
6	7.41	115.6	7.39	115.3	6.43	116.6	6.39	116.3	7.39	115.5	7.32	115.2	6.43	116.8	6.37	116.3
7	7.61	131.0	7.47	130.9	7.41	130.8	7.24	130.7	7.52	130.9	7.37	130.7	7.34	130.7	7.18	130.5
8	7.30	123.5	6.93	123.0	7.29	123.7	6.89	123.3	7.22	123.4	6.85	122.9	7.19	123.7	6.85	123.2
9	7.79	128.4	7.03	128.4	7.83	128.4	7.12	[c]	7.68	129.0	7.07	128.6	7.75	129.2	7.21	[d]
9a	—	121.1	—	121.1	—	120.9	—	120.8	—	120.7	—	120.5	—	120.7	—	120.3
9b	—	89.8	—	91.5	—	90.2	—	91.9	—	89.2	—	90.3	—	89.6	—	90.6
OH	6.80	—	7.35	—	6.92	—	7.42	—	7.02	—	7.40	—	7.20	—	7.63	—
1′(3a)	—	133.9	—	133.8	—	133.6	—	133.5	—	131.6	—	131.7	—	131.3	—	131.4
2′(3a)	7.24	126.7	7.34	126.8	7.26	126.7	[e]	126.8	7.31	128.8	[f]	[g]	7.56	128.9	[h]	[c]
3′(3a)	7.31	128.2	7.27	128.1	7.35	128.4	[e]	[c]	7.39	128.1	[f]	[g]	7.47	128.4	[h]	[c]
4′(3a)	7.31	128.2	7.34	128.4	7.36	128.4	[e]	[c]	7.39	128.1	[f]	[g]	7.43	128.9	[h]	[c]
1′(R^1)	3.46	30.0	3.55	30.2	—	137.5	—	[a]	3.51	30.0	3.59	30.1	—	137.6	—	[b]
2′(R^1)	—	—	—	—	7.27	128.9	7.39	[c]	—	—	—	—	7.40	130.3	[h]	[d]
3′(R^1)	—	—	—	—	7.64	130.3	7.68	[c]	—	—	—	—	7.67	128.9	7.74	[d]
4′(R^1)	—	—	—	—	7.57	128.8	7.62	[c]	—	—	—	—	7.58	128.9	7.63	[d]
1′(R^2)	9.89	—	10.22	—	9.97	—	10.28	—	3.77	48.0	3.86	48.2	3.72	48.0	3.81	48.3
									3.30		3.34		3.22		3.31	
2′(R^2)	—	—	—	—	—	—	—	—	2.35	30.4	2.43	30.4	2.32	30.3	2.41	30.3
									1.62		1.72		1.61		1.71	
3′(R^2)	—	—	—	—	—	—	—	—	1.27	20.1	1.30	20.2	1.23	20.1	1.26	20.1
									1.17		1.21		1.13		1.16	
4′(R^2)	—	—	—	—	—	—	—	—	0.86	13.8	0.89	13.8	0.83	13.7	0.86	13.7
1′(R^3)	2.77	28.0	—	136.4	2.88	28.2	—	[a]	2.80	29.2	—	137.0	2.93	29.3	—	[b]
2′(R^3)	—	—	7.25	130.7	—	—	[e]	[c]	—	—	[f]	[g]	—	—	[h]	[d]
3′(R^3)	—	—	7.35	128.3	—	—	[e]	[c]	—	—	[f]	[g]	—	—	[h]	[d]
4′(R^3)	—	—	7.35	128.4	—	—	[e]	[c]	—	—	[f]	[g]	—	—	[h]	[d]

[a] 138.3, 137.6 or 136.6.
[b] 137.8, 137.5, 137.2.
[c] 130.6, 130.5, 129.1, 129.0, 128.9, 128.8, 128.6, 128.4, 128.0.
[d] 130.5, 130.4, 130.4, 129.9, 129.3, 129.0, 128.9, 128.8, 128.5, 128.4.
[e] 7.45–7.10.
[f] 7.42–7.23, 6.99 (br s).
[g] 130.2, 129.1, 128.8, 128.6, 128.2, 128.1.
[h] 7.67–7.26 (br s).

73.4 ppm (if R^2=H) or 77.5–79.0 ppm (if R^2=Bu). The occurrence of ^{13}C NMR shifts of the thioxo group in a narrow region of 183.4–184.8 ppm, typical of the C=S group, excludes the presence of tautomeric compounds bearing a C–SH group that could theoretically arise from compounds **3a–d**. These results are consistent with those recorded from the 3-butyl analogs of compounds **3**.[4]

In only one case—starting from compound **1c** and phenyl isothiocyanate (Table 1, entry 4)—was an acyclic compound (**2d**) isolated in significant quantities. The major product appears almost entirely as the open form **2d** immediately after dissolution in DMSO-d_6. Proton chemical shifts at 10.00 and 8.98 ppm were assigned to –NHC(=S)NH– fragment, and characteristic ^{13}C resonances were observed at 187.8 (C=O), 180.4 (C=S) and 73.5 (C-3) ppm. However, the compound **2d** appears to cyclize rapidly to **3d** in DMSO-d_6 thus, a complete assignment of other resonances was impossible. The ^{1}H and ^{13}C chemical shifts of compound **3d** are given in Table 2.

The molecular rearrangement of compounds **3** was carried out in accordance with our earlier papers[4,5] by boiling in acetic acid or concentrated hydrochloric acid. The results are presented in Table 3. A suggested reaction mechanism for the rearrangement of compounds **3** (Scheme 2) is similar to that of their oxaanalogues.[1] After protonation and loss of water, cationic intermediate **A** arises and subsequently rearranges to intermediate **B** through migration of the amide group from the 3a to the 9b position. In the case of **2d**, its cyclization to **3d** must proceed in advance. Further transformation of intermediate **B** proceeds either by elimination of a proton to give spiro-compounds **4a–d**, or by addition of water and formation of two racemic 4*R**5*R** and 4*R**5*S** spiro-compounds **5e–h**. We do not exclude the possibility that compounds **5** are formed initially and subsequently dehydrate to **4** in cases when R^2=H.

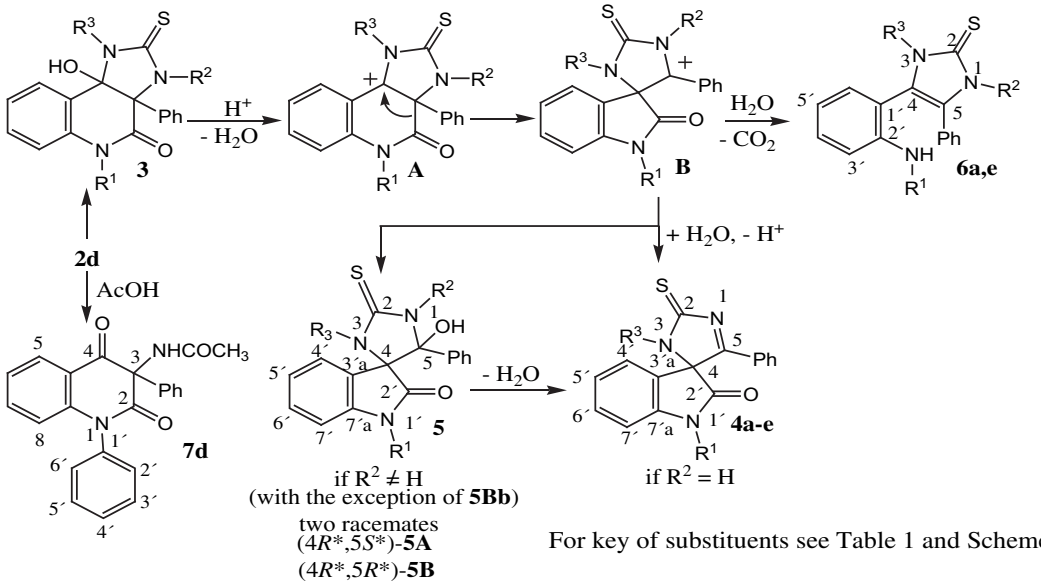
Table 3
Molecular rearrangement of compounds **2** and/or **3** in boiling AcOH (*Method A*) and concd hydrochloric acid (*Method B*)[a]

Entry	Starting compound	Method	Time (h)	Products (yield, %)
1	**3a**	*A*	2.5	**4a** (44)
2	**3a**	*B*	2	**6a** (52)
3	**3b**	*A*	3	**4b** (33), **3b** (34)
4	**3b**	*B*	3	**4b** (11), **5Ab** (19)
5	**3c**	*A*	4	**4c** (70)
6	**3c**	*B*	3	**4c** (2), **8c·HCl** (5), **9c** (11), **NPI**[b] (7)
7	**2d**	*A*	3.5	**4d** (22), **2d** (30), **7d** (13)
8	**2d**	*B*	3	**4d** (18)
9	**3e**	*A*	1	**5Ae** (18), **5Be** (29)
10	**3e**	*B*	3	**5Ae** (4), **6e** (26), **3e** (10)[c]
11	**3f**	*A*	3	**5Af** (24), **5Bf** (36)
12	**3f**	*B*	1	**5Af** (9), **5Bf** (61)
13	**3g**	*A*	3	**5Ag** (57)
14	**3g**	*B*	2	**5Ag** (58), **5Bg** (12)
15	**3h**	*A*	3	**5Ah** (19), **5Bh** (33)
16	**3h**	*B*	3	**5Bh** (37)

[a] For key of substituents see Table 1.
[b] *N*-Phenylisatin, identical to the authentic compound.
[c] Recovered starting material.

NMR spectral characteristics of compounds **4** are given in Table 4. The structure of **4a** was confirmed by single crystal X-ray diffraction, revealing distances and angles particular to the proposed bonding arrangement (Fig. 1). Compounds **5e–h** exhibit in their ^{13}C NMR spectra two sp^3-C signals in the regions of 77.2–80.6 ppm (C(4)) and 94.4–98.2 ppm (C(5)) (Table 5), whereas only one signal for an sp^3-C atom (C(4)) appears in the region of 82.5–84.3 ppm for compounds **4** (Table 4). These values are in accord with those observed for the 2-oxaanalogues of compounds **4** (76.2–77.8 ppm) and **5** (74.8–76.1 and 91.4–93.4 ppm).[1]

Two stereogenic centers at C(4) and C(5) are present in compounds **5**. Indeed, two racemates **5A** and **5B** were formed after rearrangement (Table 3) due to nonstereospecific addition of water to carbocation **B** (Scheme 2). According to TLC in several solvent systems, the corresponding pairs **5A**/**5B** differed in their R_f values, and each racemate was chromatographically pure. The structures of two epimeric racemates corresponding to **5f** were confirmed by X-ray diffraction analysis (Figs. 2 and 3). The ORTEP view of the first racemic diastereoisomer (Fig. 2) shows the presence of two



For key of substituents see Table 1 and Scheme 1

Scheme 2.

Table 4
^{1}H and ^{13}C chemical shifts (δ, ppm) of compounds **4** and **6** in DMSO-d_6

Position	**4a**		**4b**		**4c**		**4d**		**6a**		**6e**	
	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C
1	—	—	—	—	—	—	—	—	—	–215.6[a]	—	—
2	—	194.2	—	195.2	—	194.4	—	195.1	—	161.6	—	161.3
3	—	—	—	—	—	—	—	—	12.73	–217.5[a,b]	—	—
4	—	82.5	—	84.3	—	82.6	—	84.2	—	124.8	—	124.8
5	—	180.3	—	180.2	—	180.1	—	179.9	—	124.3	—	127.9
1′	—	—	—	—	—	—	—	—	—	113.0	—	112.2
2′	—	167.5	—	167.9	—	167.2	—	167.6	—	149.0	—	149.2
3′	—	—	—	—	—	—	—	—	6.72	109.9	6.58	109.6
3′a	—	121.6	—	121.8	—	121.3	—	121.7	—	—	—	—
4′	7.25	125.4	7.58	125.9	7.40	125.7	7.66	126.5	7.39	131.3	7.22	130.8
5′	7.18	124.9	7.16	124.4	7.27	125.3	7.19	125.2	6.68	115.8	6.55	115.2
6′	7.64	132.7	7.50	132.1	7.59	132.5	7.40	132.4	7.02	132.0	7.02	132.5
N*H*R[1]	—	—	—	—	—	—	—	—	—	–325.4[a,c]	—	—
7′	7.46	111.3	7.23	111.0	7.09	111.7	6.78	111.2	—	—	—	—
7a′	—	143.9	—	143.9	—	143.6	—	143.2	—	—	—	—
1′(5)	—	128.3	—	128.2	—	128.3	—	128.0	—	128.7	—	128.8
2′(5)	7.62	128.5	7.67	128.5	7.77	128.2	7.78	[d]	7.36	125.5	7.39	128.4
3′(5)	7.50	130.2	7.53	129.9	7.60	130.0	7.66	[d]	7.26	128.5	7.39	130.4
4′(5)	7.66	134.8	7.70	134.6	7.70	134.6	7.70	134.8	7.22	127.2	7.39	128.7
1′(R[1])	3.42	27.6	3.26	27.4	—	132.9	—	132.7	2.71	29.9	2.67[e]	29.9
2′(R[1])	—	—	—	—	7.65	126.7	[f]	126.3	—	—	—	—
3′(R[1])	—	—	—	—	7.70	130.2	[f]	[c]	—	—	—	—
4′(R[1])	—	—	—	—	7.60	129.4	[f]	[c]	—	—	—	—
1′(R[2])	—	—	—	—	—	—	—	—	12.73	—	4.02 3.93	44.6
2′(R[2])	—	—	—	—	—	—	—	—	—	—	1.58	30.0
3′(R[2])	—	—	—	—	—	—	—	—	—	—	1.15	19.3
4′(R[2])	—	—	—	—	—	—	—	—	—	—	0.75	13.4
1′(R[3])	2.95	30.1	—	136.7	3.11	30.2	—	135.6	3.17	31.1	3.28	32.0
2′(R[3])	—	—	7.10	128.1	—	—	7.12	[d]	—	—	—	—
3′(R[3])	—	—	7.40	129.5	—	—	[f]	[d]	—	—	—	—
4′(R[3])	—	—	7.36	129.2	—	—	[f]	[d]	—	—	—	—

[a] δ (^{15}N).
[b] ^{1}J (^{15}N,^{1}H)=98.6 Hz.
[c] ^{1}J (^{15}N,^{1}H)=93.4 Hz.
[d] 130.3, 130.1, 129.7, 129.5, 129.4, 128.6, 128.2.
[e] δ(^{1}H)=5.36 (NH).
[f] 7.61–7.22.

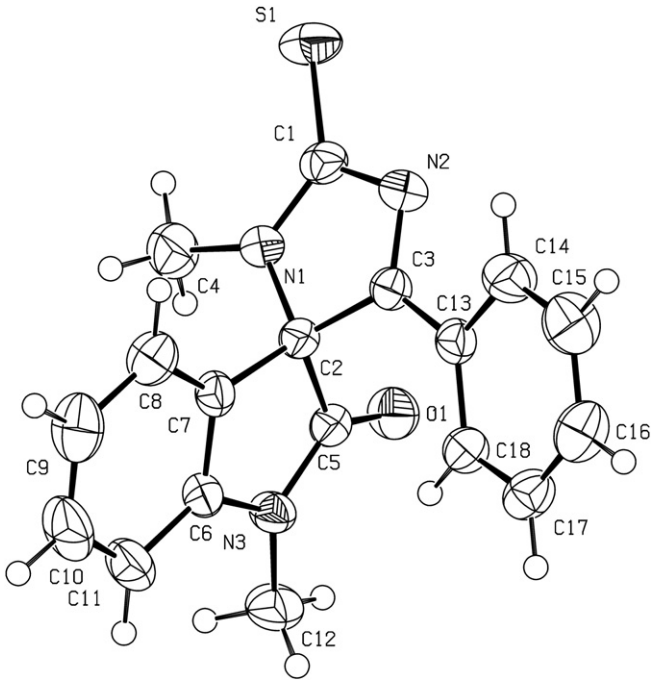


Figure 1. ORTEP view of compound **4a** showing the thermal ellipsoids at 50% probability (arbitrary spheres for H atoms). For selected interatomic distances and angles see Supplementary data.

independent molecules with 4*R*,5*S* and 4*S*,5*R* configuration ((4*R**,5*S**)-**5Af**) in the crystal unit cell. By contrast, the corresponding ORTEP view of the second epimeric racemate (Fig. 3) shows only one symmetrically independent molecule having both carbon atoms (C(4) and C(5)) in *R*,*R* configuration. Naturally, in *P*−1, the corresponding molecule with *S*,*S* configuration is also present. Therefore, this compound can be designed as (4*R**,5*R**)-**5Bf**. The biggest difference between these otherwise similar samples is the fact that the strong intermolecular O–H···O=C hydrogen contact is present between two enantiomeric forms in the case of the(4*R**,5*S**)-**5Af**, forming thus a linear chain. On the other hand, between two enantiomeric forms represented by (4*R**,5*R**)-**5Bf**, such a contact is not observed, and intramolecular hydrogen bonding takes place instead. For views of H-bonding in **5Af** and **5Bf**, see Supplementary data. The MS of corresponding pairs **5A**/**5B** is almost identical. From an analysis and mutual comparison of NMR spectra (Table 5) of the rearrangement products from **3e**–**h** it follows that **5Ae**, **5Af**, **5Ag and 5Ah** are also pure racemic diastereoisomers with (4*R**,5*S**) configuration, and that compounds **5Be**, **5Bf**, **5Bg** and **5Bh** are pure epimeric diastereoisomers with a (4*R**,5*R**) configuration. It is interesting to note, that compound (4*R**,5*S**)-**5Ab**—which bears a hydroxyl group, and could theoretically provide **4b** upon acid-catalyzed dehydration—arises simultaneously with **4b** by rearrangement of **3b** (Table 3).

In two cases (Table 3, entries 2 and 10), compounds **6** were isolated upon rearrangement of compounds **3** in concentrated hydrochloric acid. It is evident that these compounds arise by hydrolysis of the lactam ring of compounds **3** (or, perhaps,

Table 5
^{1}H and ^{13}C chemical shifts (δ, ppm) of compounds **5A** and **5B** in DMSO-d_6

Position	**5Ab**		**5Ae**		**5Be**		**5Af**		**5Bf**		**5Ag**		**5Bg**		**5Ah**		**5Bh**	
	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C
2	—	184.1	—	185.7	—	184.1	—	185.7	—	183.2	—	185.9	—	184.2	—	185.8	—	183.2
4	—	72.9	—	79.2	—	77.2	—	80.6	—	78.1	—	79.3	—	77.4	—	80.4	—	78.2
5	—	91.4	—	94.4	—	97.2	—	95.3	—	97.9	—	94.6	—	97.6	—	95.5	—	98.2
2′	—	172.1	—	171.9	—	172.0	—	172.4	—	172.7	—	171.5	—	171.5	—	172.1	—	172.3
3a′	—	121.1	—	120.4	—	121.7	—	120.4	—	121.6	—	120.1	—	121.6	—	120.1	—	121.4
4′	7.52	128.0	7.74	128.3	5.56	125.5	7.89	128.9	5.54	126.4	7.85	128.8	5.70	126.0	7.97	129.6	5.65	126.9
5′	7.10	122.4	7.21	122.3	6.61	121.5	7.11	122.0	6.47	121.2	7.28	122.9	6.63	122.2	7.16	122.6	6.52	121.8
6′	7.33	130.6	7.45	130.7	7.29	130.4	7.32	130.4	7.15	130.2	7.43	130.8	7.19	130.5	7.25	130.6	7.08	130.3
7′	6.90	108.8	6.91	108.6	7.03	108.8	6.73	108.3	6.88	108.6	6.55	108.9	6.71	108.9	6.37	108.6	6.60	108.9
7a′	—	143.4	—	144.6	—	145.3	—	144.1	—	144.9	—	144.3	—	144.7	—	143.8	—	144.4
OH	7.30	—	7.35	—	7.46	—	7.71	—	7.66	—	7.50	—	7.60	—	7.83	—	7.85	—
1′(5)	—	133.8	—	135.3	—	137.9	—	134.8	—	137.9	—	135.5	—	137.8	—	135.0	—	137.8
2′(5)	[a]	[b]	7.04	127.3	6.94	128.2	7.11	127.6	7.07	128.3	7.11	127.7	6.94	128.2	7.17	127.9	7.15	128.7
3′(5)	[a]	[b]	7.27	127.4	7.39	128.2	7.29	127.7	7.42	128.3	7.35	127.7	7.34	128.2	[c]	[d]	7.50	128.4
4′(5)	[a]	[b]	7.33	128.8	7.42	129.2	7.36	129.0	7.46	129.4	7.40	129.2	7.39	129.3	[c]	[d]	7.50	129.5
1′(R^1)	3.00	26.1	2.59	25.7	3.18	26.4	2.50	25.6	3.14	26.4	—	133.2	—	134.1	3.63	45.3	4.00	44.2
															3.54		3.07	
2′(R^1)	—	—	—	—	—	—	—	—	—	—	6.61	126.3	7.45	126.7	2.06	30.5	1.80	30.5
	—	—	—	—	—	—	—	—	—	—					2.01		1.76	
3′(R^1)	—	—	—	—	—	—	—	—	—	—	7.42	129.6	7.60	129.8	1.29	20.3	1.37	19.8
4′(R^1)	—	—	—	—	—	—	—	—	—	—	7.40	128.5	7.49	128.3	0.92	13.8	0.92	14.0
1′(R^2)	10.18	—	3.54	45.0	3.89	44.1	3.59	45.2	3.97	44.1	3.58	45.1	3.87	44.2	—	138.5	—	138.7
			3.32		2.94		3.48		3.04		3.42		2.92					
2′(R^2)	—	—	1.89	30.5	1.73	30.7	2.04	30.5	1.79	30.5	1.95	30.5	1.70	30.6	[c]	[d]	7.13	129.1
	—	—			1.66		1.97		1.73				1.62					
3′(R^2)	—	—	1.25	20.2	1.33	19.8	1.28	20.2	1.37	19.8	1.27	20.2	1.28	19.8	[c]	[d]	7.28	128.7
4′(R^2)	—	—	0.89	13.8	0.91	14.0	0.91	13.8	0.94	14.0	0.90	14.0	0.85	13.8	[c]	[d]	7.20	127.6
1′(R^3)	—	137.7	2.74	31.5	2.60	31.4	—	138.6	—	138.3	2.88	31.5	2.71	31.7	—	133.0	—	133.9
2′(R^3)	[a]	[b]	—	—	—	—	7.30	128.7	7.02	129.1	—	—	—	—	6.45	126.0	7.38	126.5
3′(R^3)	[a]	[b]	—	—	—	—	7.24	129.7	7.21	128.6	—	—	—	—	[c]	[d]	7.64	129.9
4′(R^3)	[a]	[b]	—	—	—	—	7.30	127.7	7.14	127.4	—	—	—	—	[c]	[d]	7.53	129.5

[a] 7.34–7.00.
[b] 129.7, 129.1, 128.8, 128.7, 128.2, 126.7.
[c] 7.46–7.23.
[d] 129.6, 129.5, 129.1, 128.8, 127.9, 127.7.

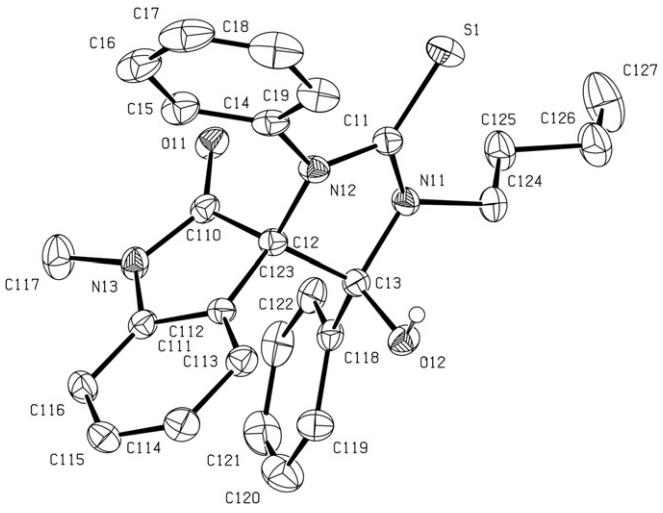


Figure 2. ORTEP view of compound **5Af** showing the thermal ellipsoids at 30% probability (arbitrary sphere for H atom, one of the isomers is shown only, H atoms except of O–H one are omitted for clarity). For selected interatomic distances and angles see Supplementary data.

intermediates **A** or **B**) with subsequent decarboxylation. The ^{15}N NMR spectra of compound **6a** (Table 4) clearly show that two NH groups (see ^{1}J (^{15}N, ^{1}H)=98.6 Hz) are present in this compound; therefore, it must contain a C=S group and the formation of the possible –SH tautomer is excluded. The structure of **6a** was confirmed by single crystal X-ray diffraction (Fig. 4).

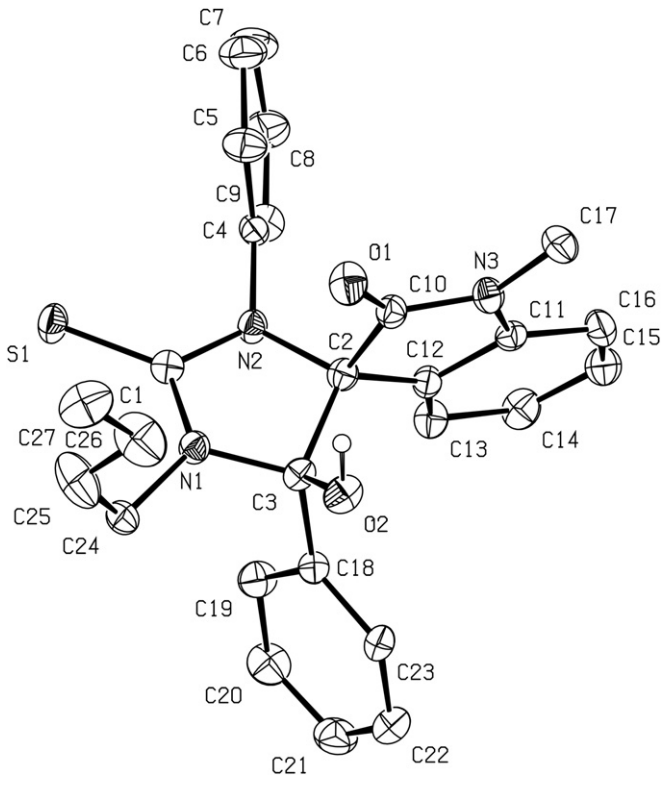


Figure 3. ORTEP view of compound **5Bf** showing the thermal ellipsoids at 30% probability (arbitrary spheres for H atoms). For selected interatomic distances and angles see Supplementary data.

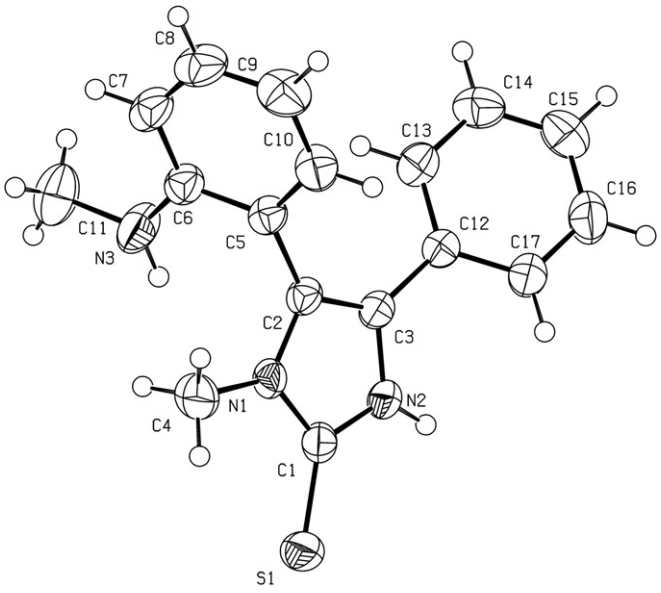
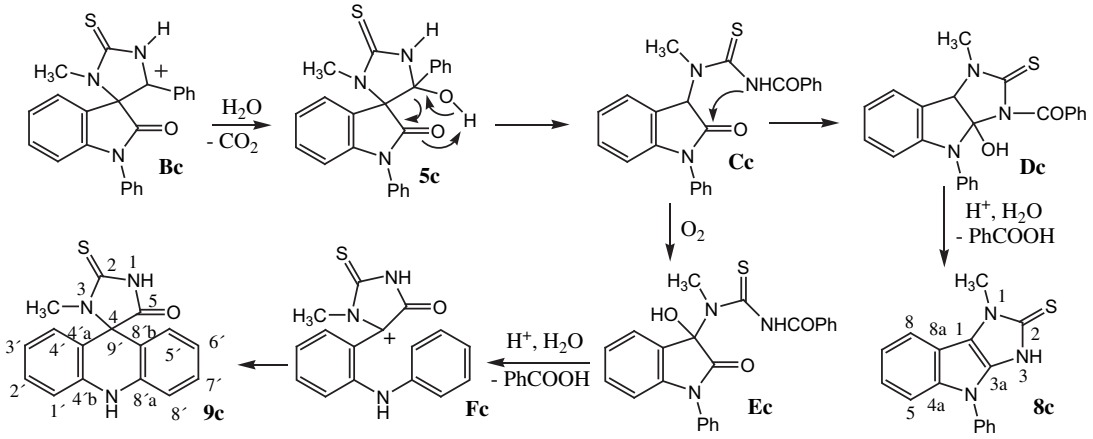


Figure 4. ORTEP view of compound **6a** showing the thermal ellipsoids at 50% probability (arbitrary spheres for H atoms). For selected interatomic distances and angles see Supplementary data.

The origin of compounds **8c** and **9c** can be explained by the transformation of the intermediate carbocation **Bc**, or of compound **5c**, which arises temporarily from **Bc** (Scheme 3). We propose that compound **5c** rearrange through intermediate **Cc** in a manner similar to that of its previously described oxaanalogue.[10,11] Nucleophilic attack in intermediate **Cc** leads to the intermediate **Dc**, which provides compound **8c** after dehydration and hydrolysis. By comparing elemental composition of compounds **3c** and **9c**, it follows that an oxidation process must proceed during the reaction. We are convinced that the intermediate **Cc** reacts with atmospheric oxygen to provide intermediate **Ec**, which after hydrolysis, protonation and elimination of benzoic acid affords carbocation **Fc** and, subsequently, compound **9c**. This proposed reaction mechanism is supported by the isolation of *N*-phenylisatine (Table 3), which arises from the hydrolysis of intermediate **Ec**.

3. Conclusions

In conclusion, we would like to emphasize that the described method affords the new spiro-oxindoles **4** and **5** in good to very good yields. The molecular rearrangement of compounds **3** not only has theoretical significance, but also offers a simple procedure for the preparation of new spiro-oxindoles suitable for biological



Scheme 3.

The structure of **6a** reveals several interesting features of the five-membered diaza heterocyclic ring. The interatomic distance C2–C3 is a bit elongated in comparison to the formal double bond distance;[7] but at the same time other distances within the same ring (C–N and C=S) are significantly shortened, indicating a high degree of conjugation within this system. Two of these molecules are interconnected via a N–H···S=C bridge (see Supplementary data). An intramolecular connection to the N–H group is precluded by the absence of the suitably positioned acceptor of electron density. Previously, we have only observed the formation of compounds similar to **6** during the rearrangement of oxaanalogues of **3** that lack a substituent at position 5.[8,9]

In one case, namely for the rearrangement of **2d**, we also isolated compound **7d** (Table 3), which arises by the acidolysis of the starting compound **2d** with acetic acid. Its structure was confirmed by the acetylation of **1d** with acetic anhydride in pyridine. Two other side reaction products (**8c**·**HCl** and **9c**) were obtained from the rearrangement of **3c** in boiling hydrochloric acid (Table 3). The structure of both products was firmly established by the assignment of all resonances undoubtedly using 2D NMR spectra.

testing, as well as for further synthetic elaboration. Compounds **4** and **5** have not been described previously in the literature; only their 2-oxoanalogues have been previously synthesized.[1] The presented results expand the number of described of compounds containing the spiro-oxindole structural motif, which notably appears in several indole alkaloids,[12] and in other compounds exhibiting various biological activities.[13,14] Our results also increase the variety of methods for preparing spiro-oxindoles.[13] At the same time, we have expanded the number of characterized compounds that contain the 4,4-spiro-2-thioxoimidazoline structural fragment. With the exception of compounds described in our previous paper,[4] relatively few compounds within this class have been described in the literature. Previously described compounds contain a cyclohexylidene,[15,16] cyclopentylidine,[16] or dihydroacridinyl group[17] as the second component of the spiro-structure. Since a number of simple *N*-substituted 2-thioxoimidazolines are known to exhibit inflammatory activity,[18] gentamycin nephrotoxicity,[19] dopamine β-hydroxylase inhibitory activity and *anti*-aggregating activity against collagen,[20] compounds **4**, **5**, and **6** have the potential to display significant biological activity.

4. Experimental

4.1. General

Melting points were determined on a Kofler block or Gallencamp apparatus. IR (KBr) spectra were recorded on a Mattson 3000 spectrophotometer. NMR spectra were recorded on a Bruker Avance spectrometer (500.13 MHz for ^{1}H, 125.76 MHz for ^{13}C, 50.68 MHz for ^{15}N) in DMSO-d_6 or $CDCl_3$. ^{1}H and ^{13}C chemical shifts are given on the δ scale (parts per million) and are referenced to internal TMS. ^{15}N chemical shifts were referred to external neat nitromethane in coaxial capillary (δ=0.0). All 2D experiments (gradient-selected (gs)-COSY, NOESY, gs-HMQC, gs-HMBC) were performed using manufacturer's software. Proton spectra were assigned using gs-COSY. Protonated carbons were assigned by gs-HMQC. Quaternary carbons were assigned by gs-HMBC. The positive- and negative-ion APCI mass spectra were measured on an ion trap analyzer Agilent LC-MSD Trap XCT-Ultra (Agilent, Palo Alto, CA, USA) within the mass range m/z=50–500. Samples were dissolved in acetonitrile and analyzed after direct injection (2 μL) at the flow rate of 400 μL/min acetonitrile. The ion source temperature was 350 °C, the APCI probe temperature was 350 °C, the flow rate and the pressure of nitrogen were 4 L/min and 45 psi, respectively. For MS/MS measurements, the isolation width of precursor ions was 4 m/z and the collision amplitude was 0.8 V. Column chromatography was carried out on Silica gel (Merck, grade 60, 70–230 mesh) using chloroform and then successive mixtures of chloroform–ethanol (in rations from 99:1 to 8:2, solvent system S1) or benzene and then successive mixtures of benzene–ethyl acetate (in rations from 99:1 to 8:2, solvent system S2). Reactions as well as the course of separation and also the purity of substances were monitored by TLC (elution systems benzene–ethyl acetate, 4:1 (S3), chloroform–ethanol, 9:1 (S4) and/or 19:1 (S5)), and chloroform–ethyl acetate, 7:3 (S6) on Alugram® SIL G/UV$_{254}$ foils (Macherey–Nagel). Elemental analyses (C, H, N) were performed with a EA 1108 Elemental Analyzer (Fisons Instrument).

X-ray *analysis*: Single crystals of **4a** and **6a** were prepared by slow crystallization from ethyl acetate and acetic acid, respectively, single crystals of **5Af** and **5Bf** were obtained by liquid diffusion method[21] using dichloromethane–hexane and acetic acid–hexane, respectively, as solvent–precipitant pairs. The X-ray data of all compounds were obtained at 150 °K using Oxford Cryostream low-temperature device on a Nonius KappaCCD diffractometer with Mo Kα radiation (λ=0.71073 Å), a graphite monochromator and the φ and χ scan mode. Data reductions were performed with DENZO-SMN.[22] The absorption was corrected by integration methods.[23] Structures were solved by direct methods (Sir92)[24] and refined by full matrix least-square based on F^2 (SHELXL97).[25] Hydrogen atoms were mostly localized on a difference Fourier map, however to ensure uniformity of treatment of crystal, all hydrogen were recalculated into idealized positions (riding model) and assigned temperature factors $H_{iso}(H)$=1.2U_{eq} (pivot atom) or of 1.5U_{eq} for the methyl moiety with C–H=0.96, 0.97 and 0.93 Å for methyl, methylene and hydrogen atoms in aromatic ring, respectively, and 0.82 Å for O–H group. Crystallographic data for structural analysis have been deposited with the Cambridge Crystallographic Data Centre, CCDC nos. 725189, 725190, 725191 and 725188 for **4a**, **5Af**, **5Bf** and **6a**, respectively. Copies of this information may be obtained free of charge from The Director, CCDC, 12 Union Road, Cambridge CB2 1EY, UK (fax: +44 1223 336033; e-mail: deposit@ccdc.cam.ac.uk or www: http://www.ccdc.cam.ac.uk). In the case of crystals (4*R**,5*R**)-**5Bf**, there are rather high *R* value parameters because bad quality of crystals.

4.2. Preparation of 3-amino-1*H*,3*H*-quinoline-2,4-diones (1)

Starting 3-substituted 3-amino-1*H*,3*H*-quinoline-2,4-diones (**1**) were prepared from corresponding 3-chloro derivatives according to the protocol described in literature.[6] One new amine was prepared.

*4.2.1. 3-Amino-1,3-diphenyl-1H,3H-quinoline-2,4-dione (**1c**).* To a stirred suspension of powdered ammonium chloride (5.35 g, 100 mmol) and potassium carbonate (27.65 g, 200 mmol) in DMF (250 mL), a solution of 3-chloro-1,3-diphenyl-1*H*,3*H*-quinoline-2,4-dione (17.4 g, 50 mmol) in DMF (125 mL) was added dropwise at 0 °C. The stirring was continued at rt for 24 h. The reaction mixture was poured into ice-water (2 L) and precipitated amine **1c** was filtered off. From the filtrate, the second part of the amine **1c** was extracted with benzene (five times, 100 mL each). The collected extracts were dried over anhydrous sodium sulfate, evaporated to dryness and the residue was crystallized from benzene–hexane. Combined portions of crude product **1c** were dissolved in hydrochloric acid (18%, 300 mL) and the solution was washed three times with benzene (each 100 mL). Aqueous layer was made alkaline with concentrated aqueous ammonia, the precipitated amine was filtered off, dried and crystallized from benzene. Yield 8.5 g (52%) of colourless plates, mp 158–160 °C (benzene), R_f 0.21 (S3); IR: 3388, 3318, 3061, 3032, 1709, 1675, 1598, 1491, 1460, 1336, 1299, 1245, 1191, 1158, 1105, 1073, 1033, 982, 945, 874, 836, 807, 765, 698, 690, 646, 595, 562, 515 cm^{-1}. ^{1}H NMR (DMSO-d_6): δ 2.70 (s, 2H, NH_2), 6.40 (d, J=8.2 Hz, 1H, H-8), 7.20 (m, 1H, H-3), 7.35 (m, 1H, H-4′(3-Ph)), 7.41 (m, 2H, H-3′(3-Ph) and H-5′(3-Ph)), 7.45 and 7.25 Hz (br s), 2H, H-2′(N–Ph) and H-6′(N–Ph)), 7.49 (m, 1H, H-7), 7.52 (m, 2H, H-2′(3-Ph) and H-6′(3-Ph)), 7.60 (m, 1H, H-4′(N–Ph)), 7.69 (m, 2H, H-3′(N–Ph) and H-5′(N–Ph)), 7.86 (d, J=7.8 Hz, 1H, H-5); ^{13}C NMR (DMSO-d_6): δ 71.8 (C-3), 116.7 (C-8), 120.3 (C-4a), 123.4 (C-6), 125.9 (C-2′(3-Ph) and C-6′(3-Ph)), 127.5 (C-5), 128.4 (C-4′(3-Ph)), 129.0 (C-4′(N–Ph)), 129.1 (C-3′(3-Ph) and C-5′(3-Ph)), 130.3 (C-2′(N–Ph) and C-6′(N–Ph)), 130.5 (C-3′(N–Ph) and C-5′(N–Ph)), 135.8 (C-7), 137.7 (C-1′(N–Ph)), 140.3 (C-1′(3-Ph), 143.4 (C-8a), 172.0 (C-2), 193.4 (C-4). Positive-ion APCI-MS: m/z 329 $[M+H]^+$ (100%); positive-ion APCI-MS/MS of m/z 328: 312 $[M+H-NH_3]^+$, 284 $[M+H-NH_3-CO]^+$ (100%). Anal. Calcd (found) for $C_{21}H_{16}N_2O_2$: C 76.81 (76.62); H 4.91 (4.97); N 8.53 (8.61).

4.3. General method for the preparation of 3-thioureido-1*H*,3*H*-quinoline-2,4-diones (2) and 9b-hydroxy-3a-phenyl-1,2,3,3a-tetrahydro-2-thioxo-5*H*-imidazo[4,5-*c*]quinolin-4(9b*H*)-ones (3)

Phenyl isothiocyanate (0.144 mL, 1.2 mmol) or methyl isothiocyanate (88 mg, 1.2 mmol) was added to the cooled (0 °C) and stirred solution of **1** (1 mmol) in chloroform (5 mL). After stirring at rt for 3 h, the solution was heated to reflux for the time given in Table 1. The course of the reaction was monitored by TLC. After cooling and evaporating in vacuo to dryness, the residue was crystallized from appropriate solvent. In the case of the reaction of **1a** with phenyl isothiocyanate, the residue was column chromatographed. Yields are given in Table 1, NMR data are presented in Table 2.

*4.3.1. 1,5-Dimethyl-9b-hydroxy-3a-phenyl-1,2,3,3a-tetrahydro-2-thioxo-5H-imidazo[4,5-c]quinolin-4(9bH)-one (**3a**).* Colourless needles, mp 235–238 °C (ethyl acetate), R_f 0.68 (S4); IR: 3401, 3264, 2975, 2931, 1671, 1657, 1604, 1473, 1393, 1361, 1286, 1223, 1175, 1147, 1135, 1108, 1094, 1080, 1066, 1041, 1027, 977, 909, 853, 807, 762, 726, 703, 674, 650, 588, 570 cm^{-1}. Positive-ion APCI-MS: m/z 340 $[M+H]^+$ (100%), 322 $[M+H-H_2O]^+$, 306, 267 $[M+H-CH_3NCS]^+$; positive-ion APCI-MS/MS of m/z 340: 267 $[M+H-CH_3NCS]^+$ (100%), 250 $[M+H-CH_3NHCSNH_2]^+$, 222. Negative-ion APCI-MS: m/z 338 $[M-H]^-$ (49%), 321 $[M+H-OH]^+$, 250 (100%); negative-ion APCI-MS/MS of m/z 338: 290, 281 $[M-H-C_4H_9]^-$, 205 $[M-H-C_4H_9NCS-H_2O]^-$

(100%). Anal. Calcd (found) for $C_{18}H_{17}N_3O_2S$: C 63.70 (63.91); H 5.05 (5.21); N 12.38 (12.41).

*4.3.2. 1,3a-Diphenyl-9b-hydroxy-5-methyl-1,2,3,3a-tetrahydro-2-thioxo-5H-imidazo[4,5-c]quinolin-4(9bH)-one (**3b**).* Colourless plates, mp 205–208 °C (ethyl acetate), R_f 0.36 (S4); IR: 3298, 3032, 2940, 2874, 1667, 1606, 1497, 1473, 1439, 1409, 1382, 1360, 1298, 1270, 1260, 1213, 1149, 1069, 1054, 1006, 972, 930, 910, 853, 812, 764, 711, 695, 653, 621, 577 cm^{-1}. Positive-ion APCI-MS: *m/z* 402 $[M+H]^+$ (100%), 267 $[M+H-C_6H_5NCS]^+$; positive-ion APCI-MS/MS of *m/z* 402: 267 $[M+H-C_6H_5NCS]^+$ (100%), 250 $[M+H-C_6H_5NHCSNH_2]^+$. Negative-ion APCI-MS: *m/z* 400 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 400: 281 $[M-H-C_6H_5NCO]^-$ (100%). Anal. Calcd (found) for $C_{23}H_{19}N_3O_2S$: C 68.81 (68.57); H 4.77 (4.59); N 10.47 (10.42).

*4.3.3. 3a,5-Diphenyl-9b-hydroxy-1-methyl-1,2,3,3a-tetrahydro-2-thioxo-5H-imidazo[4,5-c]quinolin-4(9bH)-one (**3c**).* Colourless needles, mp 241–245 °C (benzene), R_f 0.58 (S6); IR: 3223, 3011, 2973, 2933, 1680, 1604, 1489, 1458, 1398, 1347, 1301, 1261, 1227, 1152, 1132, 1071, 1031, 985, 946, 922, 824, 771, 751, 730, 710, 695, 653, 605, 573 cm^{-1}. Positive-ion APCI-MS: *m/z* 402 $[M+H]^+$ (100%), 384 $[M+H-H_2O]^+$, 368 $[M+H-H_2S]^+$, 329 $[M+H-CH_3NCS]^+$; positive-ion APCI-MS/MS of *m/z* 402: 329 $[M+H-CH_3NCS]^+$ (100%). Negative-ion APCI-MS: *m/z* 400 $[M-H]^-$ (55%), 312 (100%); negative-ion APCI-MS/MS of *m/z* 400: 205 $[M-H-C_6H_5-CH_3NHCSNH_2-CO]^-$ (100%). Anal. Calcd (found) for $C_{23}H_{19}N_3O_2S$: C 68.81 (68.69); H 4.77 (4.87); N 10.47 (10.54).

*4.3.4. 3-Thioureido-1,1′,3′-triphenyl-1H,3H-quinoline-2,4-dione (**2d**).* Colourless plates, mp 217–223 °C (ethyl acetate–hexane), R_f 0.53 (S6); IR: 3346, 1698, 1651, 1599, 1561, 1529, 1493, 1462, 1339, 1325, 1301, 1266, 1247, 1161, 1114, 1069, 1027, 986, 905, 878, 837, 778, 760, 744, 696, 660, 602, 566 cm^{-1}. Positive-ion APCI-MS: *m/z* 464 $[M+H]^+$ (100%), 329 $[M+H-C_6H_5NCS]^+$; positive-ion APCI-MS/MS of *m/z* 420: 329 $[M+H-C_6H_5NCS]^+$ (100%), 312 $[M+H-C_6H_5NHCSNH_2]^+$, 284 $[M+H-C_6H_5NHCSNH_2-CO]^+$. Negative-ion APCI-MS: *m/z* 462 $[M-H]^-$ (100%), 343 $[M-H-C_6H_5NCO]^-$, 312; negative-ion APCI-MS/MS of *m/z* 462: 343 $[M-H-C_6H_5NCO]^-$ (100%). In DMSO-d_6 solution changes into the mixture of **2d** and **3d**. Anal. Calcd (found) for $C_{28}H_{21}N_3O_2S$: C 72.55 (72.45); H 4.57 (4.59); N 9.06 (9.01); S 6.92 (6.74).

*4.3.5. 9b-Hydroxy-1,2,3,3a-tetrahydro-1,3a,5-triphenyl-2-thioxo-5H-imidazo[4,5-c]quinolin-4(9bH)-one (**3d**).* Colourless cubes, mp 195–204 °C (cyclohexane–ethyl acetate), R_f 0.57 (S6); IR: 3379, 3326, 3179, 3064, 1673, 1605, 1495, 1462, 1398, 1341, 1299, 1266, 1214, 1152, 1131, 1072, 1052, 1026, 1009, 647, 629, 829, 809, 756, 709, 696, 649, 621, 608, 575 cm^{-1}. Positive-ion APCI-MS: *m/z* 464 $[M+H]^+$ (100%), 329 $[M+H-C_6H_5NCS]^+$; positive-ion APCI-MS/MS of *m/z* 420: 329 $[M+H-C_6H_5NCS]^+$ (100%), 312 $[M+H-C_6H_5NHCSNH_2]^+$, 284 $[M+H-C_6H_5NHCSNH_2-CO]^+$. Negative-ion APCI-MS: *m/z* 462 $[M-H]^-$ (100%), 343 $[M-H-C_6H_5NCO]^-$, 312; negative-ion APCI-MS/MS of *m/z* 462: 343 $[M-H-C_6H_5NCO]^-$ (100%). Anal. Calcd (found) for $C_{28}H_{21}N_3O_2S$: C 72.55 (72.45); H 4.57 (4.59); N 9.06 (9.01); S 6.92 (6.74).

*4.3.6. 3-Butyl-1,5-dimethyl-9b-hydroxy-3a-phenyl-1,2,3,3a-tetrahydro-2-thioxo-5H-imidazo[4,5-c]quinolin-4(9bH)-one (**3e**).* Colourless plates, mp 205–210 °C (benzene), R_f 0.65 (S3); IR: 3430, 2959, 2934, 2861, 1657, 1604, 1498, 1465, 1444, 1424, 1402, 1367, 1301, 1277, 1227, 1176, 1156, 1135, 1101, 1046, 981, 936, 849, 804, 774, 758, 703, 668, 652, 580, 547 cm^{-1}. Positive-ion APCI-MS: *m/z* 396 $[M+H]^+$ (100%), 378 $[M+H-H_2O]^+$, 352 $[M+H-C_3H_8]^+$, 323 $[M+H-CH_3NCS]^+$; positive-ion APCI-MS/MS of *m/z* 396: 378 $[M+H-H_2O]^+$, 323 $[M+H-CH_3NCS]^+$ (100%). Negative-ion APCI-MS: *m/z* 394 $[M-H]^-$ (40%), 250 (100%). Negative-ion APCI-MS/MS of *m/z* 394: 379 $[M-H-CH_3]^-$, 350 $[M-H-C_3H_8]^-$, 261 $[M-H-C_4H_9NCS-H_2O]^-$ (100%). Anal. Calcd (found) for $C_{22}H_{25}N_3O_2S$: C 66.81 (66.70); H 6.37 (6.42); N 10.62 (10.81).

*4.3.7. 3-Butyl-1,3a-diphenyl-9b-hydroxy-5-methyl-1,2,3,3a-tetrahydro-2-thioxo-5H-imidazo[4,5-c]quinolin-4(9bH)-one (**3f**).* Colourless cubes, mp 140–145 °C and then 199–203 °C (benzene–cyclohexane), R_f 0.47 (S3); IR: 3418, 3254, 3063, 2954, 2928, 2870, 1676, 1604, 1495, 1470, 1399, 1368, 1284, 1224, 1133, 1106, 1055, 1019, 965, 855, 751, 715, 695, 661, 593, 518 cm^{-1}. Positive-ion APCI-MS: *m/z* 458 $[M+H]^+$ (30%), 323 $[M+H-C_6H_5NCS]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 458: 323 $[M+H-C_6H_5NCS]^+$ (100%). Negative-ion APCI-MS: *m/z* 456 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 456: 412 $[M-H-C_3H_8]^-$, 337 $[M-H-C_6H_5NCO]^-$ (100%), 323 $[M-H-C_4H_9NCS-H_2O]^-$, 264 $[M-H-C_4H_9NCS-C_6H_5]^-$. Anal. Calcd (found) for $C_{27}H_{27}N_3O_2S$: C 70.87 (70.95); H 5.95 (5.71); N 9.18 (9.23).

*4.3.8. 3-Butyl-3a,5-diphenyl-9b-hydroxy-1-methyl-1,2,3,3a-tetrahydro-2-thioxo-5H-imidazo[4,5-c]quinolin-4(9bH)-one (**3g**).* Colourless plates, mp 208–211 °C (benzene), R_f 0.58 (S3); IR: 3364, 3066, 3039, 2954, 2934, 2859, 1670, 1603, 1494, 1461, 1407, 1364, 1352, 1296, 1173, 1151, 1130, 1099, 1055, 1031, 986, 942, 868, 823, 767, 751, 699, 660, 634, 622, 605, 590, 516 cm^{-1}. Positive-ion APCI-MS: *m/z* 458 $[M+H]^+$ (100%), 440 $[M+H-H_2O]^+$, 424, 414 $[M+H-C_3H_8]^+$, 385 $[M+H-CH_3NCS]^+$; positive-ion APCI-MS/MS of *m/z* 520: 385 $[M+H-CH_3NCS]^+$ (100%). Negative-ion APCI-MS: *m/z* 456 $[M-H]^-$ (15%), 312 (100%); negative-ion APCI-MS/MS of *m/z* 456: 412 $[M-H-C_3H_8]^-$ (65%), 261 $[M-H-C_6H_5NHCO-C_4H_9-H_2O]^-$ (100%). Anal. Calcd (found) for $C_{27}H_{27}N_3O_2S$: C 70.87 (70.62); H 5.95 (6.05); N 9.18 (9.31).

*4.3.9. 3-Butyl-9b-hydroxy-1,3a,5-triphenyl-1,2,3,3a-tetrahydro-2-thioxo-5H-imidazo[4,5-c]quinolin-4(9bH)-one (**3h**).* Colourless rods, mp 209–212 °C (benzene–hexane), R_f 0.44 (S3); IR: 3324, 3060, 3038, 2950, 2870, 1664, 1604, 1494, 1461, 1364, 1295, 1223, 1186, 1154, 1130, 1104, 1061, 1025, 1005, 944, 913, 809, 748, 715, 701, 660, 647, 622, 593, 536, 517 cm^{-1}. Positive-ion APCI-MS: *m/z* 520 $[M+H]^+$ (27%), 486, 385 $[M+H-C_6H_5NCS]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 520: 385 $[M+H-C_6H_5NCS]^+$ (100%). Negative-ion APCI-MS: *m/z* 518 $[M-H]^-$ (17%), 474 $[M-H-C_3H_8]^-$, 312 (100%); negative-ion APCI-MS/MS of *m/z* 518: 474 $[M-H-C_3H_8]^-$ (100%), 323 $[M-H-C_6H_5NHCO-C_4H_9-H_2O]^-$. Anal. Calcd (found) for $C_{32}H_{29}N_3O_2S$: C 73.96 (73.81); H 5.62 (5.79); N 8.09 (8.30).

4.4. General methods for the molecular rearrangement of compounds 2 and 3

Method A: The solution of starting compound **2** or **3** (1 mmol) in acetic acid (8 mL) was heated to reflux for the time given in Table 3. The course of the reaction was monitored by TLC. After cooling, the reaction mixture was evaporated to dryness in vacuo and the residue was crystallized from appropriate solvent or separated by column chromatography on silica gel. Yields are given in Table 3, NMR data are presented in Tables 4 and 5.

Method B: The solution of starting compound **2** or **3** (1 mmol) in concd hydrochloric acid (5 mL) was heated to reflux for the time given in Table 3. In same cases a small quantity of acetic acid was added to dissolution of starting compound. The course of the reaction was monitored by TLC. After cooling, the reaction mixture was evaporated to dryness in vacuo and the residue was dissolved in pyridine. The solution was evaporated to dryness and the residue was crystallized from appropriate solvent or separated by column chromatography on silica gel. In the case of starting compound **3c**, a portion of the reaction mixture was insoluble in pyridine. This

portion was filtered off with suction and recrystallized from ethanol to give **8c·HCl**.

*4.4.1. 1′,3-Dimethyl-5-phenyl-2-thioxospiro[4H-imidazol-4,3′-[3H]indol]-2′(1′H,3H)-one (**4a**).* Yellow needles, mp 236–239 °C (ethanol), R_f 0.50 (S3); IR: 2968, 2922, 1726, 1716, 1611, 1540, 1489, 1468, 1445, 1389, 1360, 1348, 1325, 1305, 1281, 1265, 1238, 1165, 1128, 1092, 1008, 938, 874, 841, 805, 779, 753, 699, 668, 614, 588, 537 cm^{-1}. For ^1H and ^{13}C NMR see Table 4. Positive-ion APCI-MS: *m/z* 322 $[M+H]^+$ (100%), 290 $[M+H-S]^+$; positive-ion APCI-MS/MS of *m/z* 322: 290 $[M+H-S]^+$, 289 $[M+H-SH]^+$, 263 $[M+H-NHCS]^+$ (100%), 247 $[M+H-NCS-OH]^+$, 222, 221. Anal. Calcd (found) for $C_{18}H_{15}N_3OS$: C 67.27 (67.39); H 4.70 (6.69); N 13.07 (13.21).

*4.4.2. 3,5-Diphenyl-1′-methyl-2-thioxospiro[imidazol-4,3′-[3H]indol]-2′(1′H,3H)-one (**4b**).* Yellowish needles, mp 242–244 °C (benzene), R_f 0.57 (S3); IR: 3087, 3066, 3033, 2936, 1716, 1610, 1543, 1492, 1471, 1447, 1387, 1361, 1347, 1305, 1282, 1159, 1132, 1112, 1074, 1024, 949, 845, 776, 755, 685, 627, 592, 581, 539 cm^{-1}. For ^1H and ^{13}C NMR see Table 4. Positive-ion APCI-MS: *m/z* 384 $[M+H]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 384: 326 $[M+NCS]^+$ (100%), 309 $[M+NCS-H_2O]^+$, 249 $[M+H-C_6H_5NCS]^+$. Anal. Calcd (found) for $C_{23}H_{17}N_3OS$: C 72.04 (72.13); H 4.47 (4.58); N 10.96 (10.81).

*4.4.3. 1′,5-Diphenyl-3-methyl-2-thioxospiro[imidazol-4,3′-[3H]indol]-2′(1′H,3H)-one (**4c**).* Yellowish plates, mp 233–236 °C (benzene), R_f 0.75 (S3); IR: 3443, 3060, 3034, 2920, 1727, 1607, 1542, 1495, 1466, 1385, 1365, 1322, 1310, 1283, 1255, 1209, 1170, 1157, 1126, 1104, 1073, 1042, 1024, 1000, 979, 938, 802, 763, 703, 680, 666, 614, 585 cm^{-1}. Positive-ion APCI-MS: *m/z* 384 $[M+H]^+$ (100%), 352 $[M+H-S]^+$; positive-ion APCI-MS/MS of *m/z* 384: 326 $[M+H-NCS]^+$ (100%). Anal. Calcd (found) for $C_{23}H_{17}N_3OS$: C 72.04 (72.31); H 4.47 (4.38); N 10.96 (10.71); S 8.36 (8.24).

*4.4.4. 2-Thioxo-1′,3,5-triphenylspiro[imidazol-4,3′[3H]indol]-2′(1′H,3H)-one (**4d**).* Yellow plates, mp 204–207 °C (benzene–hexane), R_f 0.73 (S3); IR: 3443, 3062, 3036, 1729, 1608, 1594, 1542, 1495, 1480, 1466, 1447, 1386, 1366, 1322, 1304, 1278, 1257, 1206, 1156, 1118, 1092, 1070, 1026, 1003, 984, 956, 941, 835, 813, 752, 702, 627, 616, 589, 540 cm^{-1}. Positive-ion APCI-MS: *m/z* 446 $[M+H]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 446: 413 $[M+H-SH]^+$, 388 $[M+H-NCS]^+$ (100%), 371 $[M+H-NCS-OH]^+$, 311 $[M+H-C_6H_5NCS]^+$, 283. Anal. Calcd (found) for $C_{28}H_{19}N_3OS$: C 75.48 (75.29); H 4.30 (4.31); N 9.43 (9.29).

4.4.5. (4R,5S*)-1-Butyl-5-hydroxy-3-phenyl-1′-methyl-2-thioxospiro[imidazolidine-4,3′-[3H]indol]-2′-one (**5Ab**).* Colourless rods, mp 200–210 °C (benzene–hexane), R_f 0.44 (S6); IR: 3457, 3342, 3184, 3061, 2933, 2832, 1702, 1607, 1492, 1470, 1418, 1372, 1309, 1249, 1150, 1121, 1089, 1074, 1017, 934, 888, 861, 839, 756, 746, 720, 697, 625, 571, 539 cm^{-1}. Positive-ion APCI-MS: *m/z* 402 $[M+H]^+$ (100%), 267 $[M+H-C_6H_5NCS]^+$; positive-ion APCI-MS/MS of *m/z* 402: 267 $[M+H-C_6H_5NCS]^+$ (100%), 250 $[M+H-C_6H_5NHCSNH_2]^+$. Negative-ion APCI-MS: *m/z* 400 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 400: 281 $[M-H-C_6H_5NCO]^-$ (100%), 265 $[M-H-C_6H_5NCS]^-$. Anal. Calcd (found) for $C_{23}H_{19}N_3O_2S$: C 68.81 (68.57); H 4.77 (4.59); N 10.47 (10.42).

4.4.6. (4R,5S*)-1-Butyl-1′,3-dimethyl-5-hydroxy-5-phenyl-2-thioxospiro[imidazolidin-4,3′-[3H]indol]-2′-one (**5Ae**).* Colourless rods, mp 227–232 °C (benzene), R_f 0.59 (S3); IR: 3315, 2959, 2929, 2870, 1718, 1615, 1472, 1400, 1369, 1302, 1268, 1176, 1146, 1093, 1064, 1004, 930, 862, 755, 703, 658, 643, 596 cm^{-1}. Positive-ion APCI-MS: *m/z* 396 $[M+H]^+$ (100%), 378 $[M+H-H_2O]^+$, 352 $[M+H-C_3H_8]^+$; positive-ion APCI-MS/MS of *m/z* 396: 378 $[M+H-H_2O]^+$, 323 $[M+H-CH_3NCS]^+$, 281 $[M+H-C_4H_9NCS]^+$, 258 $[M+H-C_3H_8-C_6H_5-OH]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 378: 336, 322 $[M+H-H_2O-C_4H_8]^+$ (100%), 264 $[M+H-H_2O-C_4H_8NCS]^+$. Negative-ion APCI-MS: *m/z* 394 $[M-H]^-$ (100%), 250; negative-ion APCI-MS/MS of *m/z* 394: 379 $[M-H-CH_3]^-$ (100%), 137. Anal. Calcd (found) for $C_{22}H_{25}N_3O_2S$: C 66.81 (66.69); H 6.37 (6.51); N 10.62 (10.51).

4.4.7. (4R,5R*)-1-Butyl-1′,3-dimethyl-5-hydroxy-5-phenyl-2-thioxospiro[imidazolidin-4,3′-[3H]indol]-2′-one (**5Be**).* Colourless needles, mp 174–177 °C (benzene), R_f 0.51 (S3); IR: 3455, 3065, 2957, 2930, 2869, 1721, 1613, 1467, 1408, 1368, 1297, 1262, 1163, 1094, 1071, 1005, 988, 927, 828, 754, 700, 656 cm^{-1}. Positive-ion APCI-MS: *m/z* 396 $[M+H]^+$ (15%), 378 $[M+H-H_2O]^+$ (100%), 352 $[M+H-C_3H_8]^+$; positive-ion APCI-MS/MS of *m/z* 396: 378 $[M+H-H_2O]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 378: 336, 322 $[M+H-H_2O-C_4H_8]^+$ (100%), 264 $[M+H-H_2O-C_4H_8NCS]^+$. Negative-ion APCI-MS: *m/z* 394 $[M-H]^-$ (80%), 250 (100%); negative-ion APCI-MS/MS of *m/z* 394: 379 $[M-H-CH_3]^-$ (100%), 295, 137. Anal. Calcd (found) for $C_{22}H_{25}N_3O_2S$: C 66.81 (66.62); H 6.37 (6.47); N 10.62 (10.48).

4.4.8. (4R,5S*)-1-Butyl-5-hydroxy-3,5-diphenyl-1′-methyl-2-thioxospiro[imidazolidine-4,3′-[3H]indol]-2′-one (**5Af**).* Colourless plates, mp 228–232 °C (acetic acid), R_f 0.63 (S4); IR: 3420, 3059, 2959, 2933, 2872, 1699, 1613, 1496, 1469, 1449, 1367, 1290, 1230, 1196, 1136, 1112, 1054, 1009, 940, 854, 759, 741, 696, 653, 616, 540 cm^{-1}. Positive-ion APCI-MS: *m/z* 458 $[M+H]^+$ (82%), 440 $[M+H-H_2O]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 458: 440 $[M+H-H_2O]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 440: 384 $[M+H-H_2O-C_4H_8]^+$ (100%), 325 $[M+H-H_2O-C_4H_9NCS]^+$. Negative-ion APCI-MS: *m/z* 456 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 456: 412 $[M-H-C_3H_8]^-$, 357 $[M-H-C_4H_9NCO]^-$ (100%), 342 $[M-H-C_4H_8NCS]^-$, 137. Anal. Calcd (found) for $C_{27}H_{27}N_3OS$: C 70.87 (70.92); H 5.95 (6.01); N 9.18 (9.23).

4.4.9. (4R,5R*)-1-Butyl-5-hydroxy-3,5-diphenyl-1′-methyl-2-thioxospiro[imidazolidine-4,3′-[3H]indol]-2′-one (**5Bf**).* Colourless plates, mp 168–170 °C (benzene–hexane), R_f 0.74 (S4); IR: 3458, 3058, 2955, 2932, 2870, 1703, 1611, 1494, 1468, 1447, 1411, 1360, 1294, 1262, 1187, 1135, 1105, 1068, 1027, 1004, 942, 835, 785, 754, 734, 695, 663, 641, 606 cm^{-1}. Positive-ion APCI-MS: *m/z* 458 $[M+H]^+$ (82%), 440 $[M+H-H_2O]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 458: 440 $[M+H-H_2O]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 440: 384 $[M+H-H_2O-C_4H_8]^+$ (100%), 325 $[M+H-H_2O-C_4H_9NCS]^+$. Negative-ion APCI-MS: *m/z* 456 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 456: 412 $[M-H-C_3H_8]^-$, 357 $[M-H-C_4H_9NCO]^-$ (100%), 342 $[M-H-C_4H_8NCS]^-$, 137. Anal. Calcd (found) for $C_{27}H_{27}N_3OS$: C 70.87 (70.75); H 5.95 (6.04); N 9.18 (9.02).

4.4.10. (4R,5S*)-1-Butyl-5-hydroxy-1′,5-diphenyl-3-methyl-2-thioxospiro[imidazolidine-4,3′-[3H]indol]-2′-one (**5Ag**).* Colourless needles, mp 251–253 °C (ethyl acetate), R_f 0.69 (S3); IR: 3360, 3321, 3062, 2961, 2929, 2871, 1731, 1611, 1594, 1500, 1468, 1372, 1300, 1260, 1236, 1214, 1174, 1140, 1104, 1061, 988, 930, 862, 764, 701, 655, 591 cm^{-1}. Positive-ion APCI-MS: *m/z* 458 $[M+H]^+$ (100%), 440 $[M+H-H_2O]^+$, 426, 414 $[M+H-C_3H_8]^+$; positive-ion APCI-MS/MS of *m/z* 458: 440 $[M+H-H_2O]^+$ (100%), 343 $[M+H-C_4H_9NCS]^+$, 320 $[M+H-C_3H_8-C_6H_5-OH]^+$, 312, 284, 208. Negative-ion APCI-MS: *m/z* 456 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 456: 412 $[M-H-C_3H_8]^-$ (100%), 341 $[M-H-C_4H_9NCS]^-$, 284 $[M-H-2\times C_6H_5-H_2O]^-$. Anal. Calcd (found) for $C_{27}H_{27}N_3O_2S$: C 70.87 (70.81); H 5.95 (6.14); N 9.18 (9.03).

4.4.11. (4R,5R*)-1-Butyl-5-hydroxy-1′,5-diphenyl-3-methyl-2-thioxospiro[imidazolidine-4,3′-[3H]indol]-2′-one (**5Bg**).* Colourless

cubes, mp 145–149 °C (cyclohexane), R_f 0.79 (S3); IR: 3378, 3059, 2953, 2932, 2870, 1725, 1610, 1500, 1453, 1397, 1370, 1310, 1258, 1235,1200, 1180, 1106, 1054, 994, 883, 805, 753, 700, 671, 583 cm^{-1}. Positive-ion APCI-MS: *m/z* 458 $[M+H]^+$, 440 $[M+H-H_2O]^+$ (100%), 426, 414 $[M+H-C_3H_8]^+$; positive-ion APCI-MS/MS of *m/z* 458: 440 $[M+H-H_2O]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 440: 384 $[M+H-H_2O-C_4H_8]^+$ (100%), 326 $[M+H-H_2O-C_4H_8NCS]^+$, 284 $[M+H-H_2O-C_4H_9NCO-C_4H_9]^+$. Negative-ion APCI-MS: *m/z* 456 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 456: 412 $[M-H-C_3H_8]^-$, 339 $[M-H-H_2O-C_4H_9NCO]^-$, 284 $[M-H-H_2O-2\times C_6H_5]^-$, 282, 136. Anal. Calcd (found) for $C_{27}H_{27}N_3OS$: C 70.87 (71.02); H 5.95 (6.05); N 9.18 (9.00).

4.4.12. (4R,5S*)-1-Butyl-5-hydroxy-1′,3,5-triphenyl-2-thioxospiro[imidazolidine-4,3′-[3H]indol]-2′-one (**5Ah**).* Yellow cubes, mp 154–158 °C (benzene–cyclohexane), R_f 0.75 (S3); IR: 3435, 3060, 2959, 2929, 2872, 1735, 1719, 1612, 1597, 1499, 1466, 1453, 1400, 1368, 1295, 1263, 1228, 1210, 1178, 1134, 1118, 1061, 1010, 993, 939, 921, 848, 757, 738, 700, 669, 658, 609, 551, 517 cm^{-1}. Positive-ion APCI-MS: *m/z* 520 $[M+H]^+$ (75%), 502 $[M+H-H_2O]^+$ (100%), 488 $[M+H-S]^+$, 476 $[M+H-C_3H_8]^+$, 382 $[M+H-C_3H_8-C_6H_5-OH]^+$; positive-ion APCI-MS/MS of *m/z* 520: 502 $[M+H-H_2O]^+$ (96%), 405 $[M+H-C_4H_9NCS]^+$, 387 $[M+H-C_4H_9NCS-H_2O]^+$, 382 $[M+H-C_3H_8-C_6H_5-OH]^+$ (100%). Negative-ion APCI-MS: *m/z* 518 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 518: 474 $[M-H-C_3H_8]^-$, 419 $[M-H-C_4H_9NCO]^-$,403 $[M-H-C_4H_9NCS]^-$, 399 $[M-H-C_6H_5NCO]^-$, 284 $[M-H-C_4H_9NCS-C_6H_5NCO]^-$ (100%). Anal. Calcd (found) for $C_{32}H_{29}N_3OS$: C 73.96 (73.81); H 5.62 (5.79); N 8.09 (8.02).

4.4.13. (4R,5R*)-1-Butyl-5-hydroxy-1′,3,5-triphenyl-2-thioxospiro[imidazolidine-5,3′-[3H]indol]-2′-one (**5Bh**).* Colourless cubes, mp 195–199 °C (benzene–hexane), R_f 0.78 (S3); IR: 3530, 3432, 3061, 2957, 2930, 2869, 1709, 1611, 1594, 1497, 1465, 1448, 1406, 1364, 1295, 1264, 1233, 1210, 1174, 1116, 1075, 1025, 901, 789, 749, 732, 699, 664, 605, 510 cm^{-1}. Positive-ion APCI-MS: *m/z* 520 $[M+H]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 520: 446 $[M+H-H_2O-C_4H_8]^+$ (100%), 387 $[M+H-H_2O-NHCS-C_4H_8]^+$, 295. Negative-ion APCI-MS: *m/z* 518 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 518: 474 $[M-H-C_3H_8]^-$, 419 $[M+H-C_4H_9NCO]^-$, 403 $[M+H-C_4H_9NCS]^-$, 399 $[M+H-C_6H_5NCO]^-$, 359, 344, 300, 284 $[M+H-3\times C_6H_6]^-$ (100%). Anal. Calcd (found) for $C_{32}H_{29}N_3OS$: C 73.96 (73.87); H 5.62 (5.81); N 8.09 (7.93).

*4.4.14. 3-Methyl-4-(2-methylamino)phenyl-5-phenyl-1H-imidazole-2(3H)-thione (**6a**).* Yellowish cubes, mp 280–286 °C (ethanol), R_f 0.38 (S3); IR: 3392, 3046, 2905, 2816, 2762, 1634, 1599, 1574, 1515, 1493, 1458, 1427, 1381, 1317, 1278, 1254, 1222, 1171, 1132, 1092, 1065, 1021, 961, 949, 911, 857, 836, 781, 760, 693, 681, 649, 616, 545, 530 cm^{-1}. Positive-ion APCI-MS: *m/z* 296 $[M+H]^+$ (100%), 264 $[M+H-S]^+$; positive-ion APCI-MS/MS of *m/z* 296: 279 $[M+H-NH_3]^+$, 264 $[M+H-S]^+$, 240, 237 $[M+H-NHCS]^+$, 222 $[M+H-NHCS-CH_3]^+$, 207 $[M+H-NHCS-2\times CH_3]^+$ (100%). Negative-ion APCI-MS: *m/z* 294 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 294: 279 $[M-H-CH_3]^-$ (100%), 262 $[M-H-S]^-$, 237, 220 $[M+H-NHCS-CH_3]^+$. Anal. Calcd (found) for $C_{17}H_{17}N_3S$: C 69.12 (69.01); H 5.80 (5.97); N 14.22 (14.08).

*4.4.15. 1-Butyl-3-methyl-4-(2-(methylamino)phenyl)-5-phenyl-1H-imidazole-2(3H)-thione (**6e**).* Colourless cubes, mp 210–212 °C (benzene–cyclohexane), R_f 0.51 (S3); IR: 3448, 3310, 3048, 2958, 2933, 2971, 2817, 1605, 1573, 1517, 1496, 1447, 1410, 1384, 1315, 1206, 1171, 1143, 1070, 1023, 935, 764, 750, 706, 642, 523 cm^{-1}. Positive-ion APCI-MS: *m/z* 352 $[M+H]^+$ (100%), 320 $[M+H-S]^+$; positive-ion APCI-MS/MS of *m/z* 352: 318, 296 $[M+H-C_4H_8]^+$ (100%), 279 $[M+H-CH_3NCS]^+$, 240, 207. Negative-ion APCI-MS: *m/z* 350 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 350: 277 $[M-H-CH_3NCS]^-$, 262, 235 $[M-H-C_4H_9NCS]^-$, 220 $[M-H-C_4H_9NCS-CH_3]^-$ (100%). Anal. Calcd (found) for $C_{21}H_{25}N_3S$: C 71.75 (71.69); H 7.17 (7.29); N 11.95 (11.82).

*4.4.16. 3-Acetamido-1,3-diphenylquinoline-2,4(1H,3H)-dione (**7d**).* Colourless rods, mp 280–283 °C (benzene), R_f 0.13 (S3); IR: 3227, 1719, 1684, 1640, 1598, 1536, 1492, 1461, 1372, 1340, 1299, 1251, 1190, 1159, 1111, 1071, 1037, 1006, 969, 853, 773, 748, 711, 664, 624, 586, 558, 538, 513 cm^{-1}. ^1H NMR (DMSO-d_6): δ 1.99 (s, 3H, CH_3), 6.45 (d, *J*=8.2 Hz, 1H, H-8), 7.21 (m, 1H, H-6), 7.50 (br m, 7H, H-3′, H-5′, H-2″, H-3″, H-4″, H-5″ and H-6″), 7.58 (m, 1H, H-7), 7.62 (tt, *J*=7.7 and 1.5 Hz, 1H, H-4′), 7.70 (br m, 2H, H-2′ and H-6′), 7.85 (dd, *J*=7.9 and 1.6 Hz, 1H, H-5), 9.51 (br s, 1H, NHCO). ^{13}C NMR (DMSO-d_6): δ 21.4 (CH_3), 71.8 (C-3), 116.8 (C-8), 119.7 (C-4a), 123.4 (C-6), 127.5 (C-2″ and C-6″), 128.1 (C-4′), 128.9 (C-3′ and C-5′), 129.1 (C-5), 129.4 (C-3″ and C-5″), 129.5 (C-4″), 130.7 and 130.4 (C-2′ and C6′), 132.9 (C-1″), 135.1 (C-7), 137.5 (C-1′), 143.0 (C-8a), 169.6 (NHCO), 170.4 (C-2), 190.1 (C-4). Positive-ion APCI-MS: *m/z* 371 $[M+H]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 371: 329 $[M+H-NCO]^+$ (100%), 312 $[M+H-NHCS]^+$, 284. Negative-ion APCI-MS: *m/z* 369 $[M-H]^-$ (44%), 250 $[M-H-C_6H_5NCO]^-$ (100%), 208 $[M-H-C_6H_5NCO-NCO]^-$; negative-ion APCI-MS of *m/z*: 327 $[M-H-NCO]^-$, 250 $[M-H-C_6H_5NCO]^-$, 208 $[M-H-C_6H_5NCO-NCO]^-$ (100%). Anal. Calcd (found) for $C_{23}H_{18}N_2O_3$: C 74.58 (74.74); H 4.90 (4.95); N 7.56 (7.38).

By acetylation of **1d** with acetic anhydride in pyridine, compound identical to **7d** was prepared in 83% yield.

*4.4.17. 1-Methyl-4-phenylimidazo[4,5-b]indole-2(1H,3H,4H)-thione hydrochloride (**8c**·**HCl**).* Yellowish cubes, mp 252–263 (ethanol), R_f 0.21 (S6); IR: 3274, 3134, 3057, 2967, 2908, 2804, 1642, 1594, 1573, 1502, 1446, 1420, 1365, 1330, 1304, 1283, 1221, 1192, 1121, 1023, 983, 952, 920, 817, 763, 746, 701, 645, 610, 524 cm^{-1}. ^1H NMR (DMSO-d_6): δ 4.11 (s, 3H, CH_3), 7.38 (m, 1H, H-6), 7.42 (m, 1H, H-7), 7.58 (tt, *J*=6.9 and 1.8 Hz, 1H, H-4′), 7.68 (m, 1H, H-5), 7.73 (m, 4H, H-2′, H-3′, H-5′, and H-6′), 8.08 (dd, *J*=7.3 and 1.6 Hz, 1H, H-8), 10.32 (br s, 2H, protonated NH-3). ^{13}C NMR (DMSO-d_6): δ 34.7 (CH_3), 111.5 (C-5), 115.9 (C-8a), 117.3 (C-8), 121.3 (C-3a), 121.8 (C-6), 122.9 (C-8b), 123.6 (C-2′and C-6′), 124.0 (C-7), 128.2 (C-4′), 130.8 (C-3′and C-5′), 136.6 (C-1′), 138.2 (C-4a), 166.0 (C-2). Positive-ion APCI-MS: *m/z* 280 $[M+H]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 280: 265 $[M+H-CH_3]^+$, 252 $[M+H-CO]^+$ (100%), 239, 224 $[M+H-C_4H_8]^+$. Negative-ion APCI-MS: *m/z* 278 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 278: 263 $[M-H-CH_3]^-$ (100%). Anal. Calcd (found) for $C_{16}H_{14}ClN_3S$: C 60.85 (60.67); H 4.47 (4.57); N 13.31 (13.16), S 10.15 (9.91).

*4.4.18. 3-Methyl-2-thioxo-5H,10′H-spiro[imidazolidine-4,9′-acridine]-5-one (**9c**).* Colourless plates, mp 298–309 °C (ethyl acetate–hexane), R_f 0.70 (S6); IR: 3339, 3071, 2934, 2827, 2665, 1739, 1618, 1586, 1523, 1489, 1459, 1422, 1396, 1349, 1328, 1303, 1286, 1250, 1162, 1139, 1108, 990, 969, 942, 883, 836, 763, 743, 655, 604, 568, 523 cm^{-1}. ^1H NMR (DMSO-d_6): δ 2.82 (s, 3H, CH_3), 6.89 (dd, *J*=8.0 and 1.6 Hz, 2H, H-4′ and H-5′), 6.98 (m, 2H, H-3′ and H-6′), 7.06 (dd, *J*=8.2 and 1.2 Hz, 2H, H-1′ and H-8′), 7.37 (m, 2H, H-2′ and H-7′), 9.72 (s, 1H, H-10′), 12.20 (s, 1H, H-1). ^{13}C NMR (DMSO-d_6): δ 29.5 (CH_3), 70.9 (C-4), 112.6 (C-4 and C-8b), 115.3 (C-1′ and C-8′), 120.7 (C-3′ and C-6′), 126.2 (C-4′ and C-5′), 130.3 (C-2′and C-7′), 175.0 (C-5), 180.3 (C-2). ^{15}N NMR (DMSO-d_6): δ=−220.8 (^1J (^{15}N, ^1H)=96.6 Hz, CH_3–N–C(=S)–*N*H–), δ=−233.4(CH_3–*N*–C(=S)–NH–), δ=−284.9(^1J (^{15}N, ^1H)=93.9 Hz, N–10′). Positive-ion APCI-MS: *m/z* 296 $[M+H]^+$ (100%); positive-ion APCI-MS/MS of *m/z* 296: 265 $[M+H-O-CH_3]^+$. Negative-ion APCI-MS: *m/z* 294 $[M-H]^-$ (100%); negative-ion APCI-MS/MS of *m/z* 294: 221 $[M-H-CH_3NCS]^-$ (100%). Anal. Calcd (found) for

$C_{16}H_{13}N_3OS$: C 65.06 (64.84); H 4.44 (4.34); N 14.23 (13.99), S 10.86 (10.61).

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tet.2010.01.041.

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