The Question of Aromaticity in the Heteronins

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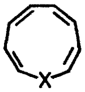
Summary Key physical characteristics of 1*H*-azonine and several *N*-substituted azonines are described and the question of "aromatic" *versus* "polyenic" heteronins is examined in the light of all available information.

RECENT work on the heteronins (**1**) and (**2**) has established fundamental differences in the physical properties of certain members of the series.[1-6]† We now report results which complement our previous information and allow for a self-consistent classification of the heteronins.



(**1**) **a**; X = O
b; X = NCO_2Et
c; X = NAc
d; X = $NCONH{\cdot}C_6H_4{\cdot}Br\text{-}p$
e; X = CH_2

(**2**) **a**; X = NH
b; X = N^-K^+
c; X = NMe
d; X = NEt
e; X = NCH_2Ph

In a previous communication on the synthesis of 1*H*-azonine,[6] (**2a**), we described the ready alcoholysis of *N*-ethoxycarbonylazonine[1,4] (**1b**). We have since used potassium azonide, (**2b**), generated in this way, in the synthesis of *N*-substituted azonines (see Table). All tabulated substances were prepared by quenching (**2b**) with the appropriate reagent at *ca.* −20°. In each instance, structural characterization involved catalytic hydrogenation (10%

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† Much of our original work with *N*-ethoxycarbonylazonine[1] (**1a**) and oxonin[2] (**1b**) was subsequently confirmed elsewhere: S. Masamune, K. Hojo, and S. Takada, *Chem. Comm.*, 1969, 1204; S. Masamune, S. Takada, and R. T. Seidner, *J. Amer. Chem. Soc.*, 1969, **91**, 7769.

Rh/C; 1 atm, −10 to 0°) to the corresponding azacyclononane, identical in all respects with a synthetic sample. In the case of (**1c**) and (**1d**) the monocycle was exclusively thermolysed to a *cis*-8,9-dihydroindole skeleton characterized both spectrally and through catalytic hydrogenation to a known *N*-substituted *cis*-8,9-octahydroindole.

Spectral and thermodynamic characteristics of azonines (**1**) *and* (**2**)

X	Quencher[a]	N.m.r.[b]	U.v.[c]	$t_{\frac{1}{2}}(50°)$[d]	$\Delta H^{\ddagger}$ [e]	$\Delta S^{\ddagger}$ [e]
NH	H_2O	τ 2·93 (2H, d, *J* 11·0 Hz), 4·00 (2H, m), 3·18 (4H, m)	252 nm (ϵ 20,500), 335 (2700)	> 40 h		
NMe	MeI	τ 4·16 (2H, d, *J* 10·5 Hz), 5·16 (2H, dd, *J* 10·5, 4·0 Hz), 3·95 (4H, m)	223 nm (ϵ 12,000), 303 (3100)	*ca.* 4 h		
NEt	EtI	τ 4·23 (2H, d, *J* 11·0 Hz), 5·21 (2H, dd, *J* 11·0, 4·0 Hz), 4·0—4·1 (4H, m)	223 nm (ϵ 10,600), 306 (2500)	*ca.* 4 h		
NCH_2Ph	$PhCH_2Br$	τ 4·08 (2H, d, *J* 11·0 Hz) 5·12 (2H, dd, *J* 11·0, 4·0 Hz), 3·9—4·0 (4H, m)		*ca.* 70 min		
NAc	AcCl	τ 3·37 (1H, d, *J* 10·0 Hz), 4·85 (1H, d, *J* 10·0 Hz), 3·6—4·3 (6H, m)	223 nm (ϵ 9000), 260(sh) (4500)	13 min	20 ± 1 kcal mol^{-1}	−10·8 e.u.
$NCONH{\cdot}C_6H_4{\cdot}Br$-*p*	*p*-$Br{\cdot}C_6H_4{\cdot}NCO$	τ 3·43 (2H, d, *J* 9·0 Hz), 4·40 (2H, d, *J* 9·0 Hz), 4·11 (4H, m)	257 nm (ϵ 22,000)	16 min	20·8 ± 1 kcal mol^{-1}	−8·5 e.u.

[a] Yields ranged from 40—60%. [b] The spectra of the first four compounds were taken in $(CD_3)_2CO$ and those of the last two in $CDCl_3$. [c] All u.v. spectra were determined in n-hexane except that of (**1d**) which was taken in acetonitrile. [d] Azonine and the three *N*-alkylazonines do not undergo clean thermal reorganization. [e] The rearrangement was monitored by n.m.r. spectroscopy in $CDCl_3$ solvent. Three first-order rate constants were evaluated in the temperature range 30—50°.

On the basis of *all* our information, it is clear that there exist two distinct classes of 10-π heteronin. These are best represented by oxonin (**1a**) and 1*H*-azonine (**2a**) and differ most obviously in terms of their resistance to heat. For example, whereas oxonin [$t_{\frac{1}{2}}(50°)$ *ca.* 2 min],[3] cyclononatetraene [**1e**; $t_{\frac{1}{2}}(50°)$ *ca.* 10 min],‡ and the azonines with a carbonyl function [**1b**—**1d**; $t_{\frac{1}{2}}(50°)$ *ca.* 12—16 min][4] thermolyse quite readily at ambient temperature, 1*H*-azonine (**2a**) and the *N*-alkylazonines (**2c**—**2e**) are quite thermally stable under the same conditions (see Table). Hence, to the extent that enhanced thermodynamic stability among π-systems is normally associated with aromaticity, we suggest that the thermally stable azonines (**2a**—**2e**) be termed aromatic and that oxonin (**1a**) and the heat-sensitive azonines (**1b**—**1d**) be referred to as polyenic.§ The close similarity in thermal behaviour of the unstable heteronins to that of cyclononatetraene provides a rational justification for our suggested classification.

The two types of heteronin also differ in many of their spectral characteristics. For example, all resonances in the ^1H n.m.r. spectrum of 1*H*-azonine occur at considerably lower fields ($\Delta\delta$ *ca.* 30—50 Hz) than do their direct counterparts in the spectra of either oxonin, or the heat-sensitive heteronins. The pronounced downfield shift in the case of (**2a**) is associated with the presence of a fairly substantial diamagnetic ring current so that this molecule is securely classed as aromatic on the basis of its n.m.r. spectrum as well. On casual inspection the *N*-alkylazonines, which also were termed aromatic in terms of their thermal behaviour, do not appear to satisfy the n.m.r. criterion of aromaticity, as their ring protons resonate at substantially higher fields, *i.e.*, in a region of the spectrum normally reserved for normal polyenes. However, the n.m.r. spectra of these substances (**2c**, **2d**, and **2e**) do differ significantly from those of the polyenic heteronins (**1a**—**1d**) In the latter substances the α-protons resonate within a normal region, *i.e.*, they appear at a considerably lower field than either the γ- or the δ-hydrogens, while in (**2c**), (**2d**), and (**2e**) they appear at an unexpectedly high field. In fact in the latter compounds $\tau(\alpha) > \tau(\gamma,\delta)$. As these substances are quite stable thermally, we suggest that the abnormal shift of their α-protons to high field is most reasonably ascribed to the well established shielding influence that a diamagnetic ring current has on atoms not contained within the molecular plane. Significantly, the α-hydrogen pair is the one most likely to be forced out-of-

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‡ This value was estimated from the data of Boche *et al.*[7]

§ We suggest that representations (**1**) and (**2**) be used for heteronins possessing $t_{\frac{1}{2}}(50°) < 1$ h and $t_{\frac{1}{2}}(50°) > 1$ h respectively.

plane on going from (**2a**) to (**2c**), (**2d**), or (**2e**) because of non-bonded interactions with the alkyl group of the latter, which ought to be quite severe in the case of an all-*cis* planar ring the size of a heteronin.[8] That (**2b**) is probably less planar and hence less aromatic than 1*H*-azonine is also suggested quite strongly by both the greater thermal stability of the latter (*ca.* 10 times) and the u.v. characteristics of these two substances.

The u.v. spectra of the two types of heteronin differ most markedly in the position of their lowest-energy band which appears as a shoulder between 240 and 270 nm in the spectra of the labile heteronins and (**1e**), and as a definite maximum above 300 nm in the case of the stable members. The basis for these differences emerges from the results of SCF calculations by Simmons[9] which place the lowest singlets of *planar delocalized* 1*H*-azonine and oxonin at 323 nm and 346 nm, respectively. The effectiveness of theory at reproducing the observed low-energy absorption of (**2a**) (335 nm) but not of (**1a**) (252 nm) suggests that the former is planar, or very nearly so, while the latter is heavily puckered. This provisional conclusion which is also strongly supported by the striking similarity of the u.v. spectrum of 1*H*-azonine to that of D_{9h} cyclononatetraenide (maximum at 320 nm)[10] and of that of oxonin to that of cyclononatetraene (shoulder at 248 nm) and which may be cautiously extended to include the other members of the two series of heteronins,¶ illustrates the powerful influence of "π" stability on overall geometry. All the data collected on the heteronins so far, point to a gradual transition from polyenic to aromatic character on increasing the availability of the electron pair on the heteroatom. This finding may be fully rationalized in terms of the same underlying principles that led to the formulation of the simple but powerful Hückel "$4n + 2$" rule for aromatic character.

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¶ In good accord with theory which, in the case of the heteronins appears to suggest use of the position of the lowest-energy u.v. band as a reliable criterion of planarity and thus of stability, we find that a decrease in the energy of this band is invariably associated with an increase in stability of the heteronin.

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[8] For a description of the effect of ring size on non-bonded H–H interactions, see H. E. Simmons and J. K. Williams, *J. Amer. Chem. Soc.*, 1964, **86**, 3222.
[9] H. E. Simmons, personal communication.
[10] H. E. Simmons, D. B. Chesnut, and E. A. LaLancette, *J. Amer. Chem. Soc.*, 1965, **87**, 982; T. J. Katz and P. J. Garratt, *ibid.* 1964, **86**, 5194; E. A. LaLancette and R. E. Benson, *ibid.*, 1965, **87**, 1941.