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Dedicated to our friend Professor Raymond Castle, in memoriam

We report the *ab initio* study of twenty-four azolides derived from pyrrole, imidazole, pyrazole, both triazoles, tetrazole, pentazole, indole and carbazole bearing at the nitrogen atom the groups COMe, CHO, COCF$_3$ and CO$_2$Me. Theoretical values (isomerism, barriers, dipole moments, C=O stretching) are compared with experimental ones, when available, and also internally compared. A special effort has been devoted to the calculation of the absolute shieldings for the different nuclei present in azolides. At the level of calculation used (RHF/6-311G**) the results are satisfactory. To complete the nmr data from the literature, some ^{1}H, ^{13}C, ^{15}N, [17]O and ^{19}F chemical shifts have been determined.

Azolides, *i.e. N*-acylazoles, are a characteristic and well studied class of heterocyclic compounds to which two recent reviews have been devoted, one covering the synthetic aspects [1] and the other, the structural properties [2]. The aim of the present paper is, besides reporting for the first time, high-level *ab initio* calculations of these compounds, to compare some experimental results, when available, to calculated properties such as geometries, populations, rotational barriers, dipole moments, $\nu_{C=O}$ stretchings and nmr chemical shifts. If the comparison theory-experiment is reasonably good, then the calculated values would be used to predict some unknown properties of azolides.

The selection of compounds was made taking into account that *N*-acetyl derivatives are the most representative and the best studied of azolides. Therefore, all these derivatives **1**-**12** have been calculated. For the other N-COR substituents, only some examples have been studied, in general, when experimental data were known. The twenty-four compounds are represented in Figure 1.

Assuming that azolides are planar or close to planarity, we have named the two conformations which result from rotation about the N-CO bond, *E* and *Z*, depending on the position of the oxygen atom with regard to the nitrogen atoms of the ring (N2 to N5). In the case of indole, the *Z* conformer has the C=O group directed towards the benzene ring. These definitions are illustrated below with the cases of triazole **6** and indole **11**.
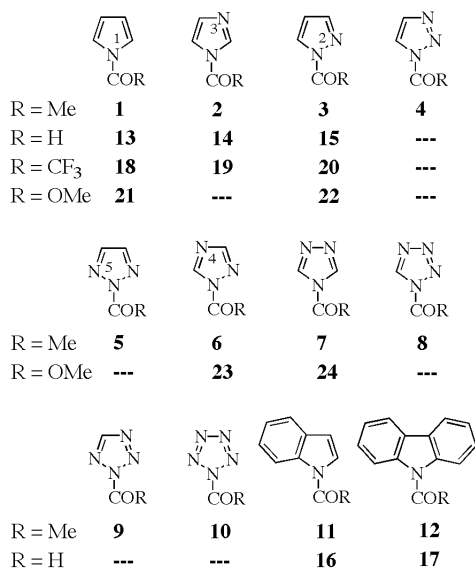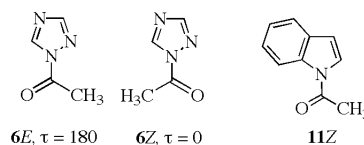

Figure 1

Computational Details.

Calculations were carried out at the RHF/6-311G** level of theory [3,4] with the Spartan (release 5.0.2) [5] and Gaussian-98 [6] programs. For all the minimum structures C_s symmetry has been assumed. The minimum or transition state nature of the structures has been confirmed by frequency calculations (no imaginary frequencies for the minimum and only one imaginary frequency for the transition states). The free energy of the systems (ΔG) has been calculated from the electronic energy, the ZPE

(zero-point energy), the thermal correction and the entropy ($T\Delta S$, T = 298.15 K). The nmr properties of the calculated molecules have been obtained using the GIAO method [7] as implemented in the Gaussian-98 program.

Results and Discussion.

I. Comparison with Experimental Results.

Geometries.

None of the molecular structures of compounds **1**-**24** has been determined by X-ray crystallography, as a survey of the Cambridge Structural Database [2,8] reveals. The two closest structures are those of 1-acetyl-4-bromopyrazole (ABRZOL10) and 1-acetylskatole (ACSKAT) which can be compared with **3** and **11**, respectively.

We have defined the torsion angle τ about the N-CO bond as 0 or 180˚ for *Z* and *E* planar conformations. All the calculated geometries are planar, although no restrictions have been imposed, for **3**, τ = 180˚ (exp. 176.7˚, ABRZOL10) and for **11**, τ = 0˚ (exp. -1.5˚, ACSKAT). The corresponding RMS for the fit are respectively, 0.03 and 0.04 for the superposition of experimental and calculated geometries showing that they are very similar.

Positional Isomerism (Acylotropy).

Most chemistry of azolides is based on the lability of the azole-COR bond. This results in the acylating properties of these compounds as well as in the facility with which the COR group migrates between the different nitrogen atoms of the azole ring [1]. If there are three or four of such atoms, two isomers are possible and the experimental evidence is collected in Table 1 together with the most relevant of the calculations.

It is clear that the very large difference in stability in the case of 1,2,4-triazole precludes the existence of 4*H*-derivatives (this is true for R = Me and for R = OMe, **23/24**). For the two other compounds, the calculated values correspond to 95:5 of **5/4** and 97:3 of **6/7**, in reasonable agreement with the experiments.

A further possible comparison is between azolide isomerism and azole tautomerism. There is abundant literature on *ab initio* calculations concerning NH-azoles, 1,2,3-triazole [9-11], 1,2,4-triazole [11] and tetrazole [12]. Nevertheless, these calculations corresponding to different levels of theory, for the sake of consistency, we decided to repeat them at the RHF/6-311G** level used for the

Table 1

Differences in free energy (kcal mol^{-1}) between the most stable isomers of *N*-acetylazoles and the most stable NH-tautomers
(in all cases, the valuse refer to parent unsubstituted compounds)

| Azole | No. | Isomers (N-COCH$_3$) | | Experimental [2] | Tautomers (NH) | |
		Diff.	More stable isomer		Diff.	More stable tautomer
1,2,3-Triazole	**4***E*/**5**	-1.5	2*H*	2*H*>1*H* [a]	-4.7	2*H*
1,2,4-Triazole	**6***E*/**7**	10.2	1*H*	1*H* [b]	6.9	1*H*
Tetrazole	**8***E*/**9***E*	2.2	1*H*	1*H*>2*H* [c]	1.6	2*H*

[a] The 1*H*-isomer can be isolated by it isomerizes to the 2*H*-isomer; at the equilibrium, at room temperature, there is a 95:5 mixture; [b] No azolides derived from 4*H*-1,2,4-triazole (C-substituted) are known; [c] Few azolides derived from 2*H*-tetrazole (C-substituted) are reported.

Table 2

Differences in Free Energy (kcal mol^{-1}) Between Rotamers of Azolides (*E*/*Z* Isomerism)

Compound	Azole	*N*-subs.	Diff(*E*/*Z*) (Table 1)	Exp. ΔG (^{1}H NMR) [2]
2	Imidazole	COMe	-0.1	0.2-0.4[a]
14	"	CHO	0.2	0.5-0.7[a]
19	"	COCF$_3$	-0.1	0.3[b]
3	Pyrazole	COMe	7.4	very large[c]
15	"	CHO	5.6	no data
20	"	COCF$_3$	4.0	no data
22	"	CO$_2$Me	1.4	0.2[b]
4	1*H*-1,2,3-Triazole	COMe	7.1	very large[b]
6	1*H*-1,2,4-Triazole	COMe	6.9	very large[b]
23	"	CO$_2$Me	1.2	0.8[b]
8	1*H*-Tetrazole	COMe	6.5	very large[b]
9	2*H*-Tetrazole	COMe	0.2	unknown comp.
11	Indole	COMe	-2.0	-1.3[b]
16	"	CHO	-0.2	-0.3[b]

[a] Depends on the solvents; [b] Determined in only one solvent; [c] Experimentally, no Z isomer is observed.

Table 3

Barriers (kcal mol^{-1}) to the Rotation of the COR Group in Azolides

Compound	Azole	*N*-subs.	Calculated barrier	Exp. $\Delta G^{\ddagger}$ (^{1}H NMR) [2]
1	Pyrrole[a]	COMe	12.7[b]	12.1
13	"	CHO	13.3	14.0
2	Imidazole	COMe	11.8	10.6
14	"	CHO	13.7	11.7
19	"	COCF$_3$	11.0	10.2
22	Pyrazole	CO$_2$Me	11.8[c]	10.4
23	1*H*-1,2,4-Triazole	CO$_2$Me	11.8 ($E \rightarrow Z$)	10.9
23	"	"	10.6 ($Z \rightarrow E$)	10.1
16	Indole	CHO	15.6	14.9
12	Carbazole	COMe	8.6	9.5[d]
17	"	CHO	14.8	14.9

[a] Absolute value of the free energy: -360.5817 hartrees; [b] A B3LYP/6-31G* calculation yields also a barrier of 12.7 kcal mol^{-1}; [c] Average value of the $E \rightarrow Z$ and $Z \rightarrow E$ barriers; [d] From ^{13}C NMR experiments.

azolides. The differences are also reported in Table 1. Note that the most stable isomer and tautomer agree although the values are different in the case of triazoles. We already described the experimental parallelism between isomeric and tautomeric equilibria, in the absence of perturbations such as steric effects or hydrogen bonds [13].

Rotational Isomerism.

All azolides exist in two conformations, *E* and *Z*, excepting "symmetrical" derivatives, pyrroles (**1**, **13**, **18**, **21**), 2*H*-1,2,3-triazole (**5**), 4*H*-1,2,4-triazoles (**7**, **24**), pentazole (**10**) and carbazoles (**12**, **17**). We have defined Diff(*E/Z*) as the difference in total energy of the *Z* isomer minus that of the *E* isomer, thus, Diff(*E/Z*) is > 0 when the *E* isomer is more stable than the *Z* one and < 0 in the opposite case.

We have reported in Table 2 the result of the calculations and the experimental evidence. The agreement is satisfactory, taking into account that we are comparing calculated free energies corresponding to isolated molecules in the gas phase with experimental values determined by nmr in solution between -100 ˚C and room temperature (they appear to be rather insensitive to solvent effects). The calculated differences decrease in the order COMe > CHO > COCF$_3$ >> CO$_2$Me in the case of pyrazole. In the case of the methoxycarbonyl residue, the second oxygen somewhat blurs the difference between *Z* (C=O close to the N-2 lone pair) and *E* (OMe close to the N-2 lone pair).

Rotational Barriers.

Some barriers about the N-COR bond in azolides have been measured; they are much weaker than in amides, due to the fact that the N1 lone pair of the azole is part of the aromatic sextet. We have collected in Table 3 only the calculated barriers for which there are some experimental data to compare with.

Although no electron correlation has been introduced, the RHF/6-311G** calculations yield reasonable values as

a regression of experimental values versus the calculated ones shows [Equation (1)].

Exp. (kcal mol^{-1}) = (0.90±0.14) Calc. (kcal mol^{-1}), R^2 = 0.82 (1)

Note, however, that concerning the experimental values of Table 3, high energy barriers (such as those of compounds **13** and **16**) were measured at room or even at high temperature while low energy barriers (for instance, **12**) were determined at very low temperatures and, therefore, they are not directly comparable.

Dipole Moments.

The few experimental values (Table 4) are reproduced by the calculations but it is not possible to interpolate such experimental values using the two calculated ones in order to determine the *E/Z* ratios. In the case of **1**, where by symmetry *E* and *Z* are identical, the calculated value is 0.3 D higher than the experimental one. For compounds **3** and **4**, only the more stable *E* isomer has to be considered, therefore, 1.86 D has to be compared with 1.55-1.85 and 1.84 with 2.09. In the indole derivative **11**, the most stable isomer is the *Z* one (3.22 *vs* 2.97 D). Finally, the most interesting case, that of imidazole **2** where both isomers coexist, it appears that the experimental values (2.81-2.96) are intermediate, but it would be imprudent to calculate the percentages of *E* and *Z* forms (remember that μ^2 and not μ should be used).

Table 4

Dipole Moments of Azolides: μ in D;
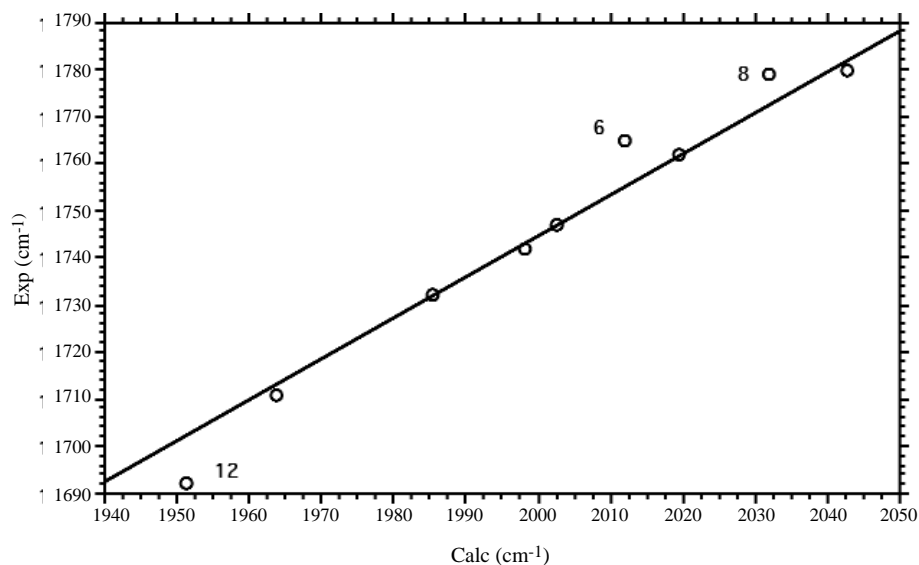Experimental Values for Dioxane Solutions at 25 °C

Compound	*E*	*Z*	Exp. [2]
1	2.87	2.87	2.54
2	2.28	4.19	2.81-2.96
3	1.86	5.06	1.55-1.85
6	1.84	3.99	2.09
11	2.50	3.22	2.97

Infrared Spectroscopy ($\nu_{C=O}$ Stretching).

For 1-acetylazoles **1**, **2**, **3**, **4**, **5**, **6**, **8**, **11** and **12**, for which the $\nu_{C=O}$ stretching is known [2], we have plotted the experimental values against the calculated ones (Figure 2). The best fit corresponds to equation (2).

$\nu_{C=O}$ exp. (cm^{-1}) = 0.872 $\nu_{C=O}$ calc. (cm^{-1}), n = 9, R^2 = 1.000 (2)

The scale factor, 0.87, is close to those reported for HF/6-31G* (0.89) [14] and HF/6-31G** (0.82) [15] methods. Equation (2) predicts for 1-acetylpentazole **10**, a $\nu_{C=O}$ = 1814 cm^{-1}.

(**1**, **12**, **17**). 3) Compounds for which only average signals have been observed (**5**, **21**, **22**, **23**). In this case we have used the average absolute shieldings.

[1]H Nmr Results.

The number of available chemical shifts is 81. An examination of the residuals of a first regression using all the data shows that the largest residues correspond to the four formyl groups. Excluding them from the regression, equation (3) is obtained. The intercept corresponds to the absolute shielding of the proton of tetramethylsilane (exp. : 30.84 ppm) [17]. The four formyl groups belong to equation (4).

Nmr Spectroscopy.

Experimental Aspects.

When we started the comparison of the calculated absolute shieldings σ (486 values: 153 ^{1}H; 204 ^{13}C; 86 ^{15}N; 38 [17]O and 5 ^{19}F) with literature data [2],we realized that the number of experimental values was not sufficient, especially concerning ^{15}N and [17]O. Therefore we have recorded (see experimental part) the spectra of several compounds reported in Figure 1. Some of them were already described, mostly ^{1}H, but in an incomplete way due to the low field of old instruments. The results are reported in Table 5.

Comparison Experiment-Theory.

The number of calculated absolute shieldings σ is so great that we have decided not to publish them but only to discuss some relevant aspects [16]. It is necessary to remember that there are three situations: 1) Compounds with a largely predominant conformation (**2E**, **3E**, **4E**, **6E**, **8E**, **11Z**, **19E**). Only this conformation has been used. 2) Compounds where both conformers have been observed (**16E** and **16Z**) or, for symmetrical compounds, where the rotation has been blocked

δ[1]H = (30.3±0.3) – (0.92±0.01) σ[1]H, n = 77, R^2 = 0.986 (3)

δ[1]H = (25±1) – (0.67±0.05) σ[1]H, n = 4, R^2 = 0.989 (4)

Obviously, the protons are very sensitive to solvent and concentration conditions, this explains why the correlation is not so good as with other nuclei.

[13]C Nmr Results.

There are 104 experimental values which lead to equation (5). But an examination of the residuals shows that all the C=O deviate on the same side of the regression line. Therefore, we tried two other equations, one without these signals, equation (6), and the other only for carbonyl groups, equation (7).

δ^{13}C = (189.1±0.6) – (0.967±0.007) σ[13]C, n = 104, R^2 = 0.994 (5)

δ^{13}C = (186.4±0.5) – (0.942±0.006) σ[13]C, n = 88, R^2 = 0.996 (6)

δ^{13}C = (194.8±1.1) – (1.019±0.032) σ[13]C, n = 16, R^2 = 0.987 (7)

Table 5

NMR Chemical Shifts (ppm) of Some Azolides

11

16Z
(major)

16E
(minor)

17
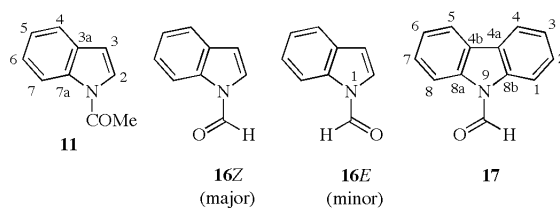
Compound	^{17}O (C=O)	^{17}O (OMe)	^{15}N (NR)	^{15}N (N2)	^{15}N (N3)	^{15}N (N4)	^{19}F (CF$_3$)
2	430.9	------	------	------	------	------	------
6	428.1	------	-133.5	-90.3	------	-123.2	------
11	407.3	------	------	------	------	------	------
16Z	397.7	------	-200.1	------	------	------	------
16E	384.6	------	-200.7	------	------	------	------
17	384.5	------	-216.9	------	------	------	------
19	423.1	------	-187.1	------	-106.7	------	-71.4
22	270.4	106.1	-162.1	-78.0	------	------	------
23	280.8	109.7	-154.5	-91.8	------	-122.5	------

Compound	C2	C3	C3a	C4	C5	C6	C7	C7a	CO	Me	CF$_3$
2	136.1	-----	-----	130.3	115.9	-----	-----	-----	166.3	22.4	-----
6	-----	152.7	-----	-----	143.1	-----	-----	-----	167.8	21.7	-----
11	125.0	108.5	130.1	120.4	123.2	124.6	116.1	135.1	168.3	23.3	-----
16Z	125.3	110.2	130.8	120.9	124.5	125.0	115.8	133.6	159.8	-----	-----
16E	121.8	110.9	130.4	121.7	124.0	124.4	109.4	134.5	156.4	-----	-----
19	136.7[a]	-----	-----	132.2	116.4	-----	-----	-----	153.0[b]	-----	114.8[c]
22	-----	143.8	-----	108.5	130.3	-----	-----	-----	149.2	54.2	-----
23	-----	153.3	-----	-----	145.4	-----	-----	-----	147.7	55.2	-----

Carbazole special numbering

	C1	C2	C3	C4	C4a	C4b	C5	C6	C7	C8	
17	120.4	124.4	127.5	116.5	136.9	137.4	109.7	126.7	124.0	119.9	-----
	C8a	C8b	-----	-----	-----	-----	-----	-----	CHO	-----	-----
	125.8	125.8	-----	-----	-----	-----	-----	-----	157.2		

Compound	H2	H3	H4	H5	H6	H7	H4'	H5'	H6'	H7'	N-R
2	8.14	-----	7.08	7.46	-----	-----	-----	-----	-----	-----	2.59 (Me)
6	-----	7.85	-----	8.76	-----	-----	-----	-----	-----	-----	2.53 (Me)
11	7.24	6.54	7.54	7.28	7.34	8.47	-----	-----	-----	-----	2.45 (Me)
16Z[d]	7.34	6.74	7.62	7.34	7.39	8.41	-----	-----	-----	-----	9.13 (H)
16E[e]	7.78	6.78	7.64	7.32	7.35	7.70	-----	-----	-----	-----	9.44 (H)
19	8.17	-----	7.11	7.48	-----	-----	-----	-----	-----	-----	-----
22	-----	7.48	6.17	7.90	-----	-----	-----	-----	-----	-----	3.81 (OMe)
23	-----	7.90	-----	8.70	-----	-----	-----	-----	-----	-----	3.97 (OMe)

Carbazole special numbering

	H1	H2	H3	H4	H5	H6	H7	H8	-----	-----	CHO
17	7.93	7.43	7.51	8.52	7.66	7.46	7.40	7.92	-----	-----	9.59 (H)

[a] $^5J_{CF}$ = 2.6 Hz; [b] $^2J_{CF}$ = 42.6 Hz; [c] $^1J_{CF}$ = 287.3 Hz; [d] 67%; [e] 33%.

The experimental absolute shielding of the carbon in tetramethylsilane is 188.1 ppm [17], thus, the calculations for the C = O carbon atoms are less satisfactory. Another carbon atom that the calculation does not reproduce well is that of the CF$_3$ group of compound **19**.
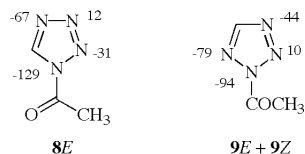
^{15}N Nmr Results.

There are 24 values to correlate with the calculated shieldings. The resulting equation is:

$$\delta^{15}N = -(130\pm1) - (0.75\pm0.02)\, \sigma^{15}N, \quad n = 24,$$
$$R^2 = 0.988\ (8)$$

The intercept, -130 ppm, is not far away from the absolute shielding of nitromethane, -117.5 ppm, the reference substance used in ^{15}N nmr spectroscopy [17] (note that nitromethane is one of these special molecules which are difficult to calculate).

The calculated values predict that it will be easy to determine the position of the acetyl group in tetrazole since the chemical shifts should be very different. 1-Acetyltetrazole **8** should exist exclusively in the *E* -conformation while 2-acetyltetrazole **9** should be a mixture of *E* and *Z* conformers.

8*E*   **9***E* + **9***Z*

^{17}O Nmr Results.

Thanks to the results we have obtained (Table 5) it has been possible to test the validity of the calculations. Note that the range is very large, from about 105 ppm (**O**Me), to 275 (**C**OOMe) to 400 ppm (**C**OR). The absolute shielding of water is 322 ppm [17].

$$\delta^{17}O = (305 \pm 2) - (0.86 \pm 0.02) \, \sigma^{17}O, \; n = 11,$$
$$R^2 = 0.996 \quad (9)$$

For compounds not measured, the values obtained using equation (9), indicate that this nucleus is very sensitive to structural changes, near 55 ppm between 1-acetylindole **11***Z* (407.3 ppm) and 1-acetylpentazole **10** (461.1 ppm) and about 8 ppm between *E* and *Z* isomers of 1-acetyl-imidazole **2**. Isomer **2***E* should appear at 425.0 ppm and isomer **2***Z* at 416.7 ppm (exp. 430.9 ppm, Table 5). This sensitivity of ^{17}O chemical shifts has already been noted and used for structural purposes [18-20].

^{19}F Nmr Results.

The calculated ^{19}F shieldings of the trifluoroacetyl groups cannot be discussed since there is only one experimental data (-71.4 ppm, **19**, Table 5). Note, that the calculated values are rather insensitive to structural changes.

II. Discussion of the Calculated Values.

One of the advantages of theoretically calculated properties is that they are internally consistent. The experimental values correspond to different conditions, for instance, different solvents, temperatures, publications, resolution of the spectrometers, and so on, while all the calculations have been carried out with the same method (SCF/6-311G**).

The barriers for the acetyl derivatives of azoles **1**-**10** can be decomposed into a sum of effects reflecting the structure of the azole. Of the different descriptors (N atoms in α or β position, *E* versus *Z* configuration), a

Table 6

Factorial Contribution to the Rotational Barriers

Azole/*N*-substituent	No	Conformation	Contribution
Pyrrole	**1**	*E* = *Z*	2.50
Imidazole	**2**	*E*	2.38
Imidazole	**2**	*Z*	2.38
Pyrazole	**3**	*E*	2.69
Pyrazole	**3**	*Z*	1.93
1*H*-1,2,3-triazole	**4**	*E*	2.85
1*H*-1,2,3-triazole	**4**	*Z*	1.35
2*H*-1,2,3-triazole	**5**	*E* = *Z*	2.03
1*H*-1,2,4-triazole	**6**	*E*	2.58
1*H*-1,2,4-triazole	**6**	*Z*	1.77
4*H*-1,2,4-triazole	**7**	*E* = *Z*	2.40
1*H*-tetrazole	**8**	*E*	2.72
1*H*-tetrazole	**8**	*Z*	1.35
2*H*-tetrazole	**9**	*E*	1.75
2*H*-tetrazole	**9**	*Z*	1.70
Pentazole	**10**	*E* = *Z*	1.55
Indole	**11**	*E*	2.42
Indole	**11**	*Z*	2.66
Carbazole	**12**	*E* = *Z*	2.12
COMe			4.74
CHO			5.97
COCF$_3$			4.67
CO$_2$Me			5.41

statistical analysis shows that the barrier depends only on the presence of nitrogen atoms in the α and β positions.

$$\Delta G^{\ddagger} = 12.6 - 5.2\ N\alpha(Z) + 1.7\ N\alpha(E) - 1.0\ N\beta,\ n = 16,$$
$$R^2 = 0.955\ (10)$$

The resulting equation (10) shows that one nitrogen atom in α position Z to the oxygen atom of the acetyl group lowers the barrier considerably (-5.2 kcal mol^{-1}) because it destabilizes the ground state of the Z configuration (N and O lone pairs in proximity).

If one wants to discuss all azolides together it is necessary to decompose the barriers into the product of two terms, one representing the different azoles (from pyrrole to carbazole in their E and Z conformations) and the other the four acyl residues (Table 6). We have already used such non-additive models in the case of 2-substituted benzimidazoles [21]). The barriers predicted by the model are simply obtained by multiplying the two contributions. Three examples will illustrate the approach. For compound **1** (Table 3, $\Delta G^{\ddagger} = 12.7$ kcal mol^{-1}), the model yields 2.50 (pyrrole) * 4.74 (acetyl) = 11.9 kcal mol^{-1}. The $\Delta G^{\ddagger}$ of compound **10** (7.3 kcal mol^{-1}, not reported) results from the product of 1.55 (pentazole) and 4.74 (acetyl). For a compound that has not been calculated, such as 2-trifluoro-acetyl-2H-1,2,3-triazole , the model predicts 2.03 * 4.67 = 9.5 kcal mol^{-1}.

Concerning the N-acyl residues, the order decreases in the sense CHO > CO$_2$Me > COMe $\geq$ COCF$_3$, that is, for the same azole, the largest barriers are those of the N-formyl derivatives. On the other side, as expected from the electron-withdrawing properties of "pyridine-like" nitrogen atoms, when the number of nitrogen atoms increases, from pyrrole to pentazole, the barriers decrease.

Conclusion.

Even without electron correlation, simple SCF/-6-311G** calculations allow to reproduce most of the properties of azolides, if not absolute values at least, relative ones which are proportional to the measured ones. The fit of equations (1) to (10) is good enough to show that from the calculated values an estimation of the experimental properties is possible, even for compounds so elusive as acetylpentazol (**10**).

EXPERIMENTAL

All compounds used for the nmr experiments reported in Table 5 were described in references [1] and [2]. Nmr spectra were obtained, using standard pulse sequences, on a Bruker DRX 400 spectrometer working at 400.13, 100.62, 40.56, 54.26 and 376.46 MHz for ^{1}H, ^{13}C, ^{15}N, ^{17}O and ^{19}F respectively. Chemical shifts (δ in ppm) are given from internal deuteriochloroform (CDCl$_3$) (7.26 for ^{1}H and 77.0 for ^{13}C) and external nitromethane, deuterium oxide (D$_2$O) and trichlorofluoromethane (CCl$_3$F) for ^{15}N, ^{17}O and ^{19}F respectively. Digital resolutions being of 0.2 for ^{1}H and ^{19}F and 0.6 for ^{13}C, ^{15}N and ^{17}O. The concentration was 200-300 mg of azolide in 0.5 mL of CDCl$_3$. The spectra were recorded at room temperature (300 K) save those of **16** and **17** (230 K). Bidimensional experiments were used in the case of compounds **16** and **17** to connect ^{1}H and ^{13}C signals. Absolute values of the free energies can be obtained from one of the authors (I.A., E-mail: <ibon@iqm.csic.es>).

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