Acyl Derivatives of Cyclic Secondary Amines. Part 2.[1] Dynamic ^1H and ^{13}C Nuclear Magnetic Resonance Studies on Bis- and Tris-amides: Equilibria of *syn-anti* Interconversion

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Variable-temperature ^1H and ^{13}C n.m.r. spectra are reported for 1,3-diacylimidazolidines, 1,3-diacylhexahydropyrimidines, and 1,3,5-triacylhexahydro-*sym*-triazines. Peaks for the individual conformers found at low temperature were assigned by using model compounds, from relative intensities, and by internal consistencies. Conformer populations are deduced and compared with those calculated assuming energy differences arise only from dipole–dipole interactions and good agreement is noted.

Restriction to rotation about the N–CO bond of amides has been the subject of intense study, and for monoamides the structural influences on the equilibria and kinetics of the *syn-anti* interconversion are well understood.[2] However, much less is known regarding polyamides. Conformational properties of polyamides are obtained from n.m.r. studies of the conformation of model diamides derived from *trans*-cyclohexane-1,2-carboxylic acid and different aliphatic amines,[3] and piperazine or *NN'*-dimethylethylenediamine and aliphatic or aromatic carboxylic acids.[4] Signals for the different configurational isomers in amides and diamides have been assigned using paramagnetic shifts induced by $Eu(fod)_3$ complexes.[5] Indeed, the investigation of dynamic n.m.r. spectra involving more than two different species has been relatively limited. N.m.r. investigation of thiophene-2,5-dicarboxaldehyde has been done in liquid crystals.[6] Rotational isomerism of *NN'*-dimethyl-α,ω-bis(benzoylamino)alkanes[7] and 1,3,5-trinitrosohexahydro-*sym*-triazine[8] has been studied using variable-temperature ^1H n.m.r. spectra. Stereoisomerisation of *NN'*-diacetyl-*NN'*-dimethylhydrazine using variable-temperatue ^1H n.m.r. spectra has been studied and a discussion about the mechanism of stereoisomerisation is also available.[9]

We have previously synthesised[1] 1,3-diacylimidazolidines (**1**), (**2**), 1,3-diacylhexahydropyrimidines (**9**), (**10**), and 1,3,5-triacylhexahydro-*sym*-triazines (**11**), (**12**). We report here a study of the relative stabilities of their *syn*- and *anti*-conformers as determined by low-temperature n.m.r.

1,3-Diacylimidazolidine Conformational Equilibria from ^1H *N.m.r. Spectra.*—At 50 °C for (**1**) and at 25 °C for (**2**), these compounds showed a 2H singlet for 2-CH_2 and a 4H singlet for 4,5-C_2H_4, which demonstrates rapid rotation about both amide links (Table 1). As the temperature is lowered, these peaks broaden and split and, below −20 °C for (**1**) and below −70 °C for (**2**) (at 300 MHz), separate signals are shown for each of the three conformers (Table 1). Additionally, (**1**) shows signals for the phenyl protons at δ 7.56 as an unresolved multiplet and (**2**) for Bu^t at δ 1.28 as a singlet. On cooling, these peaks broaden and reappear respectively as a multiplet near δ 7.50 for (**1**), and as three singlets at δ 1.31, 1.28, and 1.24 for (**2**).

The CH_2 signals at low temperatures were assigned to the individual conformers by recourse to model compounds. 1,3,3-Trimethyl-2-piperidone (**7**) shows the *N*-methyl (necessarily *syn* to the carbonyl) at δ 3.00.[10] By analogy, the *syn*-methyl in *NN*-dimethylpivalamide (**6**) has been assigned to the signal at δ 2.96 and the *anti*-methyl of (**6**) to the signal at δ 3.21 in the 1H n.m.r. spectrum obtained at −40 °C.

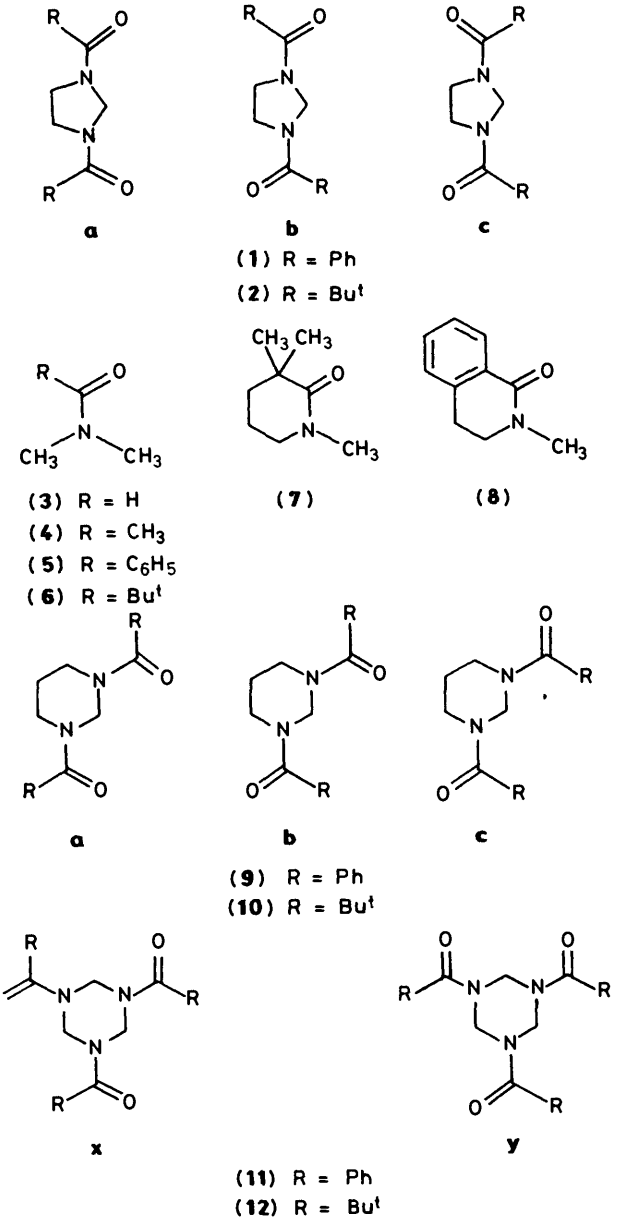

Table 1. ^{1}H N.m.r. chemical shifts, J values (Hz), and relative population (%) for 1,3-diacylimidazolidines (**1**) and (**2**)

		2-CH_2			4,5-C_2H_4					R		
T/°C	Conformer	δ	I	Populations (%)	δ	Multiplicity	J	I	Populations (%)	δ	Multiplicity	I
25[a]	(**1**)	5.20	2.00[b]		3.88	s		4.00		7.56	s	10.44
−30[c]	(**1a**)	4.95	0.07	3.5	4.03	s		0.21	5.3			
	(**1b**)	5.17	1.60	80.0	4.03	t	7	3.18	79.5	7.50	m	10.54
					3.82	t	7					
	(**1c**)	5.45	0.33	16.5	3.79	s		0.61	15.2			
25[a]	(**2**)	5.15	2.00[b]		3.85	s		4.00		1.28	s	18.00
−80[c]	(**2a**)	5.01	0.55	27.5	4.05	s		1.23	30.8	1.24[d]	s	*e*
	(**2b**)	5.12	1.40	70.0	3.93	t	6	2.71	67.7	1.28[d]	s	*e*
					3.86	t	6					
	(**2c**)	5.27	0.05	2.5	3.72	s		0.06	1.5	1.31[d]	s	*e*

t = triplet; s = singlet; m = multiplet; I = intensity. [a] 60 MHz spectrum. [b] Intensity reference standard. For low-temperature spectra, total intensity of 2.0 for these peaks taken as standard. [c] 300 MHz spectrum. [d] Tentative assignment. [e] Total intensity 18.18, individual intensities not measurable due to overlap.

Table 2. ^{13}C N.m.r. shifts [δ (p.p.m.)] for 1,3-diacylimidazolidines (**1**) and (**2**)

				Imidazolidine ring			R substituent C_6H_5 or $C(CH_3)_3$				C=O	
Compound	R	T/°C	Conformation	C-2	C-4	C-5	C-1	C-2, -6	C-3, -5	C-4		
(**1**)	C_6H_5	50[b]		62.0	45.7	45.7	135.1	127.1	128.4	130.6	168.8	
		25[b]		*c*	*c*	*c*	134.8	127.0	128.3	130.5	168.7	
		−30[d]	**a**	60.4	48.0	48.0	134.4[a]	126.9	127.3	130.8[a]	*e*	
			b	62.3	44.2	46.5	134.6[a]	127.0	128.5	130.9[a]	169.4	168.8
			c	*e*	42.8	42.8	134.7[a]	127.2	128.7	131.1[a]	168.7	
(**2**)	$C(CH_3)_3$	25[b]		62.3	45.5	45.5	38.8	27.2			175.8	
		−70[b]	**a**	61.7	46.6	46.6	38.7[a]	26.80[a]			175.3	
			b	63.7	46.5	43.6	38.6[a]	26.74[a]			175.8	175.7
			c	*e*	*e*	*e*	38.5[a]	26.70[a]			*e*	

[a] Tentative assignment. [b] 25 MHz spectrum. [c] Broad unresolved peak. [d] 75 MHz spectrum. [e] Not observed.

In the phenyl series, the model compound *N*-methyl-1,2,3,4-tetrahydro-2-isoquinolone (**8**) shows the (necessarily *syn*) N–CH_3 signal at δ 3.2.[11] *NN*-Dimethylbenzamide (**5**) at −26.6 °C in CH_2Br_2 showed signals at δ 3.38 and 3.53 for the N–CH_3 protons,[12] and by analogy with (**8**) that at δ 3.38 was assigned to the methyl *syn* to the carbonyl. Interestingly, *NN*-dimethylformamide (**3**) and *NN*-dimethylacetamide (**4**) at 25 °C show the methyl protons *syn* to the carbonyl group downfield (δ 2.98 and 2.83) with respect to the corresponding *anti* methyl protons (δ 2.81and 1.98),[13] but we consider these less satisfactory models.

Hence, in conformers **a**—**c** of (**1**) and (**2**), we expect the 2-CH_2 protons to be at highest field in **a** where they are *syn* to both carbonyls and at lowest field in **c** where they are *anti* to both carbonyls. Conversely, conformer **a** should show a singlet at lower field for the 4,5-C_2H_4 protons than the singlet for **c**. In the unsymmetrical conformer **b**, the 4,5-C_2H_4 protons should show as an AA′XX′ pattern, with the chemical shift for A nearer to that of conformer **c** and of X nearer to conformer **a**. The assignments of Table 1 follow these considerations.

The relative proportions of the three conformers can be obtained from the relative signal intensities and are shown in Table 1. Since the 2-CH_2 signals are separate singlets for the different conformers we consider them more reliable for isomer proportion deduction than the 4,5-CH_2 signals, for which the singlet for the conformers **a** and **c** overlaps with the A_2X_2 double triplets from conformer **b**.

Hence, we conclude that in the equilibrium for (**1**) at 243 K, conformer **b** is favoured over **a** by 1.51 kcal mol^{-1} and over **c** by 0.76 kcal mol^{-1} ($\Delta G°$). However, for (**2**) at 193 K conformer **b** is favoured over **a** by 0.35 kcal mol^{-1} and over **c** by 0.28 kcal mol^{-1}. These values are calculated from $\Delta G° = -RT \ln P_a/P_b$.

1,3-*Diacylimidazolidine Conformational Equilibria from* ^{13}C *N.m.r. Spectra.*—The 75 MHz spectra of (**1**) at 25 °C are near coalescence and show broadened lines for C-2, -4, and -5 which become sharp singlets at 60 °C; (**2**) shows sharp singlets for these carbons at 25 °C. At −30 °C for (**1**) and −70 °C for (**2**), signals are shown for the individual conformers (Table 2). In this case, the signals were assigned by reference to model compounds (**3**), (**4**), and particularly (**5**), in which the *N*-methyl carbons *syn* to the carbonyl group are always shielded (δ 31.1, 34.5, and 35.2 p.p.m., respectively) compared to the *anti N*-methyl carbons (δ 36.2, 37.5, and 38.9 p.p.m., respectively).[14] Additionally, we can use the different number of signals expected for the nonsymmetrical conformer **b** compared with the symmetrical conformers **a** and **c**.

Conformers (**1a**—**c**) showed a total of four signals due to C-4 and -5. Of these, the two of intermediate chemical shift are of equal intensity, much greater than the other two, and are accordingly unambiguously assigned to conformer (**1b**). From the rule stated above, carbon *syn* to the carbonyl oxygen is shielded, and thus the medium-intensity peak at δ 48.0 p.p.m. is assigned to (**1a**) and the low-intensity peak at δ 42.8 p.p.m. to (**1c**). (These assignments agree with the conformer populations deduced from the ^{1}H spectra.) For C-2, only two signals were obtained; as expected, the peak of greater intensity [(**1b**)] was at lower field than that for (**1a**) [the expected peak for the less populated isomer (**1c**) was not observed].

Compound (**2**) displayed only three peaks for C-4 and -5: two

Table 3. ^{1}H N.m.r. chemical shifts and relative population (%) for 1,3-diacylhexahydropyrimidines (**9**) and (**10**)

		2-CH_2			4(6)-CH_2		5-CH_2		R	
				Population						
T/°C	Compound	δ	I	(%)	δ	I	δ	I	δ	I
25[a]	(**9**)	5.17(s)	2.00[b]		3.81(t)[c]	4.00	1.80(m)	2.02	7.40(m)	10.40
−30[d]	(**9a**)	5.04(s)	0.79	39.7	3.95(m)	*e*	1.84(m)[f]	*g*	7.34(m)	*h*
	(**9b**)	5.20(s)	1.06	53.3	3.95(m)	*e*	1.93(m)[f]	*g*	7.34(m)	*h*
					3.66(m)	*e*				
	(**9c**)	5.57(s)	0.14	7.0	3.66(m)	*e*	1.84(m)[f]	*g*	7.34(m)	*h*
25[a]	(**10**)	5.31(s)	2.00[b]		3.76(t)[c]	4.00	1.70(m)	2.03	1.28(s)	18.00
−103[d]	(**10a**)	4.99(s)	0.16	8.0	4.41(m)	*i*	1.78(m)	*j*	1.16	*k*
	(**10b**)[l]	5.03(s)	1.84	92.0	4.41(m)	*i*	1.78(m)	*j*	1.16	*k*

t = triplet; s = singlet; I = intensity. [a] 60 MHz spectrum. [b] Intensity reference standard; at low temperature total intensity for these peaks taken as 2.0. [c] J 6 Hz. [d] 300 MHz spectrum. [e] Total intensity 4.30; individual intensities not measurable due to overlap. [f] Tentative assignment. [g] Total intensity 2.01; individual intensities not measurable due to overlap. [h] Total intensity 10.50; individual intensities not measurable due to overlap. [i] Total intensity 4.40; individual intensities not measurable due to overlap. [j] Total intensity 2.04; individual intensities not measurable due to overlap. [k] Total intensity 19.00; individual intensities not measurable due to overlap. [l] No peaks for (**10c**) observed.

Table 4. ^{13}C N.m.r. shifts [δ (p.p.m.)] for 1,3-diacylhexahydropyrimidines (**9**) and (**10**)

				Pyrimidine ring				R substituent (C_6H_5 or $C(CH_3)_3$				
Compound	R	T/°C	Confor-mation	C-2	C-4	C-5	C-6	C-1	C-2, -6	C-3, -5	C-4	C=O
(**9**)	C_6H_5	25[a]		59.8	44.3	24.9	44.3	133.2	127.4	128.4	130.3	170.1
(**9**)	C_6H_5	−40[b]	**a**	52.8	47.3	25.2[c]	47.3	134.3[c]	127.2[c]	128.4[c]	130.3[c]	169.9
			b	58.2	4.70	25.2[c]	41.8	134.0[c]	127.0[c]	128.3[c]	130.2[c]	170.6
									133.9	126.8		169.8
			c	2.8	41.7	24.0[c]	41.7	133.3[c]	126.5[c]	128.1[c]	130.0[c]	*d*
(**10**)	Bu^t	25[a]		58.3	44.9	24.9	44.9	38.7	28.00			176.8
(**10**)	Bu^t	−70[b]	**a**	58.4	47.1	25.6	47.1	39.1	28.2[c]			176.1
			b[b]	58.6	47.1	25.6	43.3	39.1	28.3[c]			176.1
							28.1[c]					175.8

[a] 25 MHz spectrum. [b] 75 MHz spectrum. [c] Tentative assignment. [d] Conformer (**10c**) not observed.

of equal and high intensity were unambiguously assigned to (**2b**); the less intense peak at lower field was assigned to (**2a**), based on the rule that the carbon *syn* to the carbonyl oxygen is shielded. Conformer (**2c**) is of low population (*cf.* ^{1}H spectra) and its peaks were not observed. Similarly, for C-2 peaks were found only for (**2a** and **b**).

The ^{13}C chemical shift assignments of the phenyl group in (**1**) and the t-butyl group in (**2**) were based on the difference in intensity of the signals, the off-resonance spectra, and (for R = C_6H_5) comparison with the spectrum of (**5**). In compound (**1**), C-2, -6 and C-3, -5 of the phenyl ring showed relatively intense signals (doublets in off-resonance spectrum), C-4 gave a medium-intensity signal (doublet in off-resonance spectrum), and C-1 a low-intensity signal (singlet in off-resonance spectrum). In compound (**2**), the quaternary carbon of $C(CH_3)_3$ showed a low intensity signal at δ *ca.* 38 p.p.m., and the methyl groups gave a very intense signal at higher field. The lowest field signal in the spectra of compounds (**1**) and (**2**) is that of the carbonyl carbons. The low-temperature ^{13}C spectrum of each shows three ^{13}C=O signals, of which two of equal intensity are assigned to the two carbonyl groups in conformer **b**. The signal due to the least populated, conformer **a** in (**1**) and **c** in (**2**), was not observed.

1,3-Diacylhexahydropyrimidine Conformational Equilibria from ^{1}H N.m.r. Spectra.—At 50 °C for (**9**), and at 25 °C for (**10**), these compounds showed a 2H singlet for 2-CH_2, which demonstrates that, just as for (**1**) and (**2**), rapid rotation occurs about both amide links (Table 3). At low temperatures for (**9**) the peaks broaden and split and at −30 °C (at 300 MHz) separate signals are shown for each of the three conformers. However, for (**10**) at −103 °C separate signals are seen only for two conformers.

Signal assignments were based on model compounds (**5**)—(**8**) as discussed earlier for imidazolidines (**1**) and (**2**). 5-CH_2 Gave an additional signal at δ *ca.* 1.9 p.p.m. The assignments of Table 3 follow these considerations; we illustrate these here with the specific example of 2-CH_2 at (**9**) and (**10**). At −30 °C, (**9**) showed three signals for 2-CH_2. Using the rule derived from model compounds, that protons *syn* to the carbonyl oxygen are shielded, the one to lowest field was assigned to (**9c**), the one to highest field to (**9a**), and the middle one to (**9b**). On similar grounds, of the two signals observed for compound (**10**), from the population ratios of (**9**) the most intense signal was assigned to (**10b**) and the remaining one at higher field was assigned to (**10a**). Assignments for the 4-, 5-, 6-CH_2 were made similarly.

Relative signal intensities and the isomer proportions from the 2-CH_2 signals are shown in Table 3. From the 4-, 6-CH_2 signals, it was not possible to derive conformer proportions because of additional coupling to 5-CH_2, and because of overlap.

We conclude that the equilibrium at 243 K for (**9**) favours conformer **b** over **a** by 0.14 kcal mol^{-1} and conformer **b** over **c** by 0.98 kcal mol^{-1} ($\Delta G°$). However, for (**10**) the equilibrium at 170 K favours conformer **b** over **a** by 0.83 kcal mol^{-1}.

1,3-Diacylhexahydropyrimidine Conformational Equilibria from ^{13}C N.m.r. Spectra.—The 75 MHz spectrum of (**9**) at 25 °C is near coalescence and shows broadened signals for C-2, -4, -5, and -6 which become sharp signals at 60 °C; (**10**) shows sharp signals for the ring carbons at 25 °C. At −40 °C signals for the individual conformers appear in the spectrum of (**9**). However,

for (**10**) at −70 °C separate signals are seen only for two conformers as was described above for the ^{1}H spectra.

Signals were assigned by reference to model compounds (**5**)—(**8**) as discussed earlier for imidazolidines (**1**) and (**2**). C-5 Gave an additional signal at δ *ca.* 24.5 p.p.m. The assignments of Table 4 follow these considerations. We illustrate this for C-2 of (**9**) and (**10**). At −40 °C (**9**) showed three signals for C-2. Using the rule that the carbon *syn* to the carbonyl is the most shielded, the most downfield signal was assigned to (**9c**), the most upfield signal to (**9a**), and the remaining one to (**9b**). On similar considerations, of the two signals seen for C-2 of (**10**), the most intense was assigned to (**10b**); since the remaining one was to higher field than (**10b**), it was assigned to (**10a**). These assignments agree with conformer populations deduced from the proton spectra. Assignments for C-4, -5, and -6 were made similarly.

1,3,5-*Triacylhexahydro*-sym-*triazine Conformational Equilibria from* ^{1}H *N.m.r. Spectra.*—At 25 °C compounds (**11**) and (**12**) showed a 6H singlet for the three CH_2 protons demonstrating rapid rotation about all three amide links. As the temperature is lowered, peaks broaden and split and at −30 °C (at 300 MHz) separate signals are observed for (**11**) for each of the two conformers. However, for (**12**) only one conformer **x** is observed even for spectra recorded as low as −110 °C in [$^2H_6$]acetone as solvent.

Signal assignments shown in Table 5 follow the same rules observed for signal assignment for imidazolidines (**1**) and (**2**), *i.e.* the protons *syn* to the carbonyl oxygen are shielded. The methylene protons for (**11**) at −30 °C showed four singlets, of which three signals were of equal intensity corresponding to conformer (**11y**). The remaining one signal was assigned to conformer (**11x**), in which all methylene protons are identical.

Relative signal intensities and the isomer proportions from the 2-, 4-, 6-CH_2 signals are also shown in Table 5.

Table 5. ^{1}H N.m.r. chemical shifts (δ) and relative population (%) for 1,3,5-triacylhexahydro-*sym*-triazines (**11**) and (**12**)

		2,4,6-CH_2		Population	N-Substituent	
T/°C	Compound	δ	*I*	(%)	δ	*I*
25[a]	(**11**)	5.30(s)	6.00[b]		7.40(s)	15.2
−20[c]	(**11x**)	5.38(s)	2.19	36.5	7.40(m)	*d*
	(**11y**)	5.26(s), 5.37(s) 5.71(s)	3.81[e]	63.5	7.40(m)	*d*
25[a]	(**12**)	5.40(s)	6.00[b]		1.35(s)	27.4
−60[c]	(**12x**)[f]	5.39(s)	6.00	100.0	1.33(s)	27.3

s = singlet; m = multiplet; *I* = intensity. [a] 60 MHz spectrum. [b] Standard reference intensity. [c] 300 MHz spectrum. [d] Total intensity 15.1; individual intensities not measurable due to overlap. [e] Total intensity of the three signals together. [f] Signals for (**12y**) not observed, even at −110 °C.

We conclude that the equilibrium at 243 K for (**11**) favours conformer **y** over **x** by 0.26 kcal mol^{-1}. However, (**12**) exists exclusively as the **x** conformer.

1,3,5-*Triacylhexahydro*-sym-*triazine Conformational Equilibria from* ^{13}C *N.m.r. Spectra.*—The 75 MHz spectra of (**11**) and (**12**) at 25 °C showed signals for the three methylene protons at δ 58.5 and 57.3 p.p.m., respectively. At −70 °C for (**11**), signals are shown for the individual conformers. However, for (**12**) only one conformer **x** is observed even at a temperature as low as −110 °C, as found in the ^{1}H spectrum. The signal assignments for the two conformers **x** and **y** of compound (**11**) and one conformer **x** of compound (**12**) were also based on the model compounds discussed earlier for imidazolidines (**1**) and (**2**). The signal assignments are shown in Table 6.

The Relative Stabilities of Bis- and Tris-amide Conformers.—The ΔE° values deduced from the low-temperature n.m.r. measurements are gathered in Table 7. These values are calculated from $P_a/P_b = (w_a/w_b) \exp\{[\Delta E(A) + \Delta E(B)]/KT\}$ where P_a and P_b are the populations deduced from the experimental intensities and w_a and w_b are the degeneracy factors of each conformer. Table 7 also contains ΔE° values calculated for the individual conformers assuming that their difference in stability arises solely from dipole–dipole interactions. The calculations were done on the corresponding formamides of compounds (**1**), (**2**), and (**9**)—(**12**).

In calculating the dipole–dipole interaction energy of the 1,3-diformylimidazolidine and 1,3-diformylhexahydropyrimidine systems, the following assumptions were made. (1) In each discrete conformer, the two molecular fragments composing the two dipoles were considered as though they were two discrete molecules separated by a constant distance. (2) The micro-dielectic constant between the two molecular fragments was taken to be 1.0.[15] (3) The interaction is along a vector R connecting the centre of atomic electron density for each molecular fragment. (4) Each atom in molecular fragment i was considered as a point charge q_i and likewise for each atom in molecular fragment j. (5) All calculations reported here on the six-membered rings were optimised for the chair conformation. Of near equal energy are twist-boat conformations, and the calculated dipole stabilities are expected to be similar.

Based on the foregoing assumptions, the centre of atomic electron density for each molecular fragment was taken as the origin for a local set of cartesian co-ordinates. The set of vectors $\{\vec{r}_i\}$ denotes the vectors originating at the centre of atomic electron density of molecular fragment i, and terminating at each atom in the molecular fragment; the set of vectors $\{\vec{r}_j\}$ was obtained in a similar manner. The magnitude of R was computed as $|\vec{R}| = (\vec{x}^2 + \vec{y}^2 + \vec{z}^2)^{1/2}$.

The values for $\vec{r}_i$, $\vec{r}_j$, $\vec{R}$, as well as the values for charges q_i and q_j were obtained by way of the ZINDO technique,[16–18] and are available from the authors on request.

Table 6. ^{13}C N.m.r. shifts [δ (p.p.m.)] for 1,3,5-triacylhexahydro-*sym*-triazines (**11**) and (**12**)

					R substituent C_6H_5 or $C(CH_3)_3$				
Compound	R	*T*/°C	Conformation	Triazine ring C-2, -4, -6	C-1	C-2, -6	C-3,-5	C-4	C=O
(**11**)	C_6H_5	25[a]		58.5	133.2	127.5	128.5	131.0	170.5
(**11**)	C_6H_5	−70[b]	**x**	58.4	133.5[c]	127.9[c]	128.7[c]	131.4[c]	170.4
			y	52.9	132.9[c]	127.8[c]	128.5[c]	131.3[c]	171.0
				58.3	132.4[c]	127.4[c]	128.3[c]	131.0[c]	170.7
				62.7	131.8[c]	126.9[c]	128.4[c]	130.7[c]	169.5
(**12**)	Bu^t	25[a]		57.3	38.7	27.6			176.6
(**12**)	Bu^t	−70[b]	**x**[d]	57.9	39.1	27.8			175.5

[a] 25 MHz spectrum. [b] 75 MHz spectrum. [c] Tentative assignment. [d] Conformer (**12y**) not observed, even at −110 °C.

Table 7. Experimental ΔE°/kcal mol^{-1} of compounds (**1**), (**2**), and (**9**)—(**12**) and calculated ΔE°/kcal mol^{-1} values for the corresponding *N*-formyl compounds

	Imidazolidines			Hexahydropyrimidines			Hexahydro-*sym*-triazines			
	Experimental[a]			Experimental[a]				Experimental[a]		
Conformer	(**1**)	(**2**)	Calc.[b]	(**9**)	(**10**)	Calc.[b]	Conformer	(**11**)	(**12**)	Calc.[c]
a	1.18	0.09	1.17	0.20	0.83	1.87	**x**	0	0	0
b	0	0	0	0	0	0	**y**	0.26	*d*	0.28
c	0.43	0.71	1.01	0.64	*d*	2.89				

[a] Calculated using $\Delta E^{\circ} = (w_a/w_b) \exp [(-\Delta E_A + \Delta E_B)/kT]$. [b] Calculated from dipole–dipole interactions. [c] Obtained from SCF calculations. [d] Not observed in n.m.r.

The dipole–dipole interaction energy was then computed using the appropriate term in the multipole expansion of the classical potential energy of two interacting systems [equation (1)].[19]

$$V_{D.D.} = (1/R^2) \sum_{ij} q_i q_j \left[\mathbf{r}_i . \mathbf{r}_j - \frac{3(\mathbf{r}_i . \mathbf{R})(\mathbf{r}_j . \mathbf{R})}{R^2} \right] \quad (1)$$

The calculated dipole–dipole interaction energies for the 1,3-diformylimidazolidine and 1,3-diformylhexahydropyrimidine systems are given in Table 7.

An examination of the experimental results in Table 7, however, indicates that no simple model based on the calculated geometries of the formamide derivatives alone is going to be totally successful in its predictions. The observed relative stabilities clearly depend on substituents. Nevertheless, the general predictions of this simple model are quite reasonable.

Experimental

The syntheses of saturated heterocyclic amides (**1**), (**2**), and (**9**)—(**12**) were previously discussed.[1] Sample solutions for n.m.r. measurements were prepared directly in 5 mm n.m.r. tubes, dissolving compound (50 mg) in solvent (3—4 ml). The solvent used was always $CDCl_3$ except when temperatures lower than −80 °C [(**10**) and (**12**)] were required when [$^2H_6$]acetone was used as the solvent. Tetramethylsilane was used as the internal reference. The solvents used for the model systems, taken from the literature, were either CCl_4 [(**3**) and (**4**)], $CDCl_3$ [(**6**)—(**8**)], or CH_2Br_2 [(**5**)].

Room-temperature ^1H spectra were recorded on a Varian EM 360L spectrometer and room-temperature ^{13}C spectra on a JEOL FX 100 spectrometer. Variable-temperature ^1H and ^{13}C spectra were recorded on a Nicolet NT 300 spectrometer.

In the thermodynamic treatment, for comparison with the calculated values, account has been taken for the circumstance that there are *two* indistinguishable forms of the unsymmetrical conformer **b** in (**1**), (**2**), (**9**), and (**10**) and *three* indistinguishable forms of the unsymmetrical conformer **y** in (**11**) and (**12**).

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