163. Stereoelectronic Aspects of the Anomeric Effect in Fluoromethylamine

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High-level *ab initio* calculations have been made for fluoromethylamine to study structural and energetic effects of the relative orientation of the N lone pair to the C–F bond. The *anti*-conformer (N lone pair *anti*-planar to the C–F bond) corresponds to the global energy minimum. It has the longest C–F distance, the shortest C–N distance, and is 7.5 kcal·mol^{-1} more stable than the related perpendicular conformation (lone pair perpendicular to the C–F bond). The *syn*-conformation also shows hallmarks of the anomeric effect: long C–F bond, short C–N bond, and energetic stability when allowance is made for the two pairs of eclipsed hydrogens. The transition state for N inversion is close to the *syn*-structure; rotation about the C–N bond is strongly coupled with this inversion process. Small bond distance changes of *ca.* 0.02 Å between parallel and perpendicular conformations are associated with dissociation energy differences of *ca.* 30 kcal·mol^{-1}. Various criteria for assessing the strength of the anomeric effect are discussed.

Introduction. – The anomeric effect is the preference of electronegative substituents at C(1) in pyranose rings to adopt the axial rather than the equatorial position [1] [2]. In a more general sense, it is concerned with interactions between occupied lone-pair orbitals on one atom and the empty antibonding σ^* orbital of an adjacent bond [3], with emphasis on the influence of such interactions on structure and reactivity^1). Since its first enunciation, the anomeric effect has continued to exercise the experimental, theoretical, and interpretative skills of a generation of chemists. There is a vast literature on the subject, which we shall not attempt to survey here (for reviews, see the monographs by *Deslongchamps* [4] and *Kirby* [5], the article by *Gorenstein* [6] and the recent critique by *Sinnott* [7]). Rather, we concentrate on several questions concerning the stereoelectronic aspects.

Given that the usual anomeric effect involves an *anti*-periplanar orientation of a lone-pair orbital with the bond in question, is there any justification for invoking a *syn* anomeric effect, involving a *syn*-planar orientation of the corresponding entities? In other words, does a *syn*-oriented lone pair provide a similar, if perhaps weaker, effect on structure and reactivity relative to an *anti*-oriented lone pair? Could a *syn*-effect have consequences, for example, when the *anti*-periplanar orientation is inaccessible? More generally, what is the conformational dependence of stereoelectronic effects? For example, how do the molecular energy and structural parameters (bond lengths and angles, *etc.*) respond to changes in relative bond–lone pair orientation?

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^{1}) Following the example of others, we shall talk about the 'anomeric effect', even though it is the generalized anomeric effect that is discussed here.

For simplicity, the main orbital interactions of importance for the anomeric effect are often discussed in terms of a HOMO-LUMO scheme, with the donor orbital playing the role of the HOMO and the σ^* acceptor orbital that of the LUMO. For our discussion, it simplifies matters to choose as donor the N lone pair of an NH_2 group. In contrast to O or F, N has only one lone-pair orbital, and, since it is higher in energy than the lone pairs of O or F, it is a better donor than them. A similar argument leads to the choice of a C–F bond as acceptor; the high electronegativity of F lowers the energies of both the σ and σ^* orbitals; the LUMO is a better acceptor. These factors point to the fluoromethylamine molecule as a suitable object of study. Although the compound does not appear to have been synthesized, this shortcoming has not deterred computational chemists from choosing the molecule as a model [8] [9]. Moreover, the *N*-benzyl-*N*-methyl and *N*-ethyl-*N*-methyl derivatives have been prepared and their ^{19}F- and ^{1}H-NMR spectra measured and interpreted [9]. To answer the questions posed in the previous paragraph, we have made calculations at the 6-31G** level [10]. The polarization functions on hydrogen, indicated by the second star, are necessary to reproduce the inversion barrier of ammonia[2]. As is well known, this basis set systematically underestimates bond lengths, particularly for polar bonds [12], but since our interest here is mainly in relative differences among bond lengths in different conformations, this is not a serious drawback for us. A few calculations including electron-correlation effects [13], as well as some with a larger basis set [13s8p]→(7s4p) + 2d on first-row atoms, and [8s]→(5s) + 2p on H-atoms [14] were made for comparison. Both extensions gave a systematic increase in bond lengths of the ground-state conformations without significant change in the relative energies.

Energy Dependence on Torsion Angle. – *Fig. 1* shows the molecular energy *E* as function of ϕ, the F–C–N–lp torsion angle (we take this torsion angle as 180° plus the average of the two F–C–N–H torsion angles, *Fig. 2*). Of the two minima, the lower (*E* set to zero) corresponds to the *anti*-planar orientation at ϕ = 180°, as expected; the other

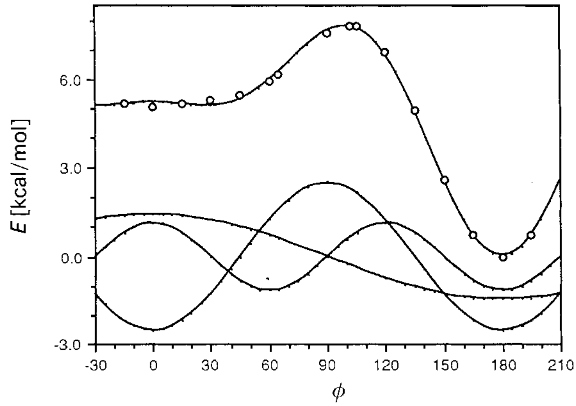

Fig. 1. *Molecular energy* E *as function of* ϕ, *the F–C–N–lp torsion angle* (see *Fig. 2*), *with three-term* Fourier *decomposition*. The circles show the calculated energies, the uppermost smooth curve the sum of the three *Fourier* terms plus a constant term.

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[2] 6-31G** gives an inversion barrier for ammonia of 5.51 kcal·mol^{-1}, while 6-31G* gives 1.0 kcal·mol^{-1} higher. The experimental value (MW) is 5.77 kcal·mol^{-1} [11].

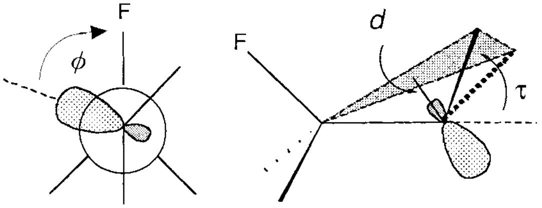

Fig. 2. *Definition of torsion angle ϕ and pyramidality measures* d *and* τ

(E = 5.08 kcal·mol^{-1}) corresponds to the *syn*-planar one at $\phi = 0$. They are separated by a saddle point (E = 7.81 kcal·mol^{-1}) at $\phi = 101.5°$, where the HOMO and LUMO orbitals are nearly orthogonal. These results are in good agreement with recent work by *Reed* and *Schleyer* who included this molecule in a comprehensive study of stereoelectronic interactions in mono- and polyfluorinated amines [15]. The energy barrier is to be compared with experimental values of 10 kcal·mol^{-1} for two *N,N*-dialkyl-substituted derivatives [9].

The pyramidality of the three bonds emanating from the N-atom was allowed to vary in response to change in ϕ; as a measure of this pyramidality we take *d*, the distance of the N-atom from the plane of its three bonded atoms (*Fig. 2*) or τ, the acute angle between the N–C bond and the H–N–H plane. The pyramidality is relatively large for the stable *anti*-structure (d = 0.34 Å, τ = 50°) and also, as might be expected, for the ϕ = 90° structure (d = 0.38 Å, τ = 60°); it is smaller (d = 0.24 Å, τ = 35°) for the less stable *syn*-conformation. Here, the energy cost of flattening the N pyramid is offset by reduction of the energetically unfavourable eclipsing interactions. In fact, the energy of the *syn*-structure (E = 5.08 kcal·mol^{-1}) is actually 0.5 kcal·mol^{-1} higher(!) than that of the corresponding structure with a completely flattened N pyramid (d = 0, E = 4.52 kcal·mol^{-1}), for which the donor orbital is now pure p in character³). The question whether there is a turning point in the energy between these two structures is discussed later.

Structural expression of the anomeric affect can be seen in *Fig. 3*, where the C–F and C–N bond lengths are plotted against the torsion angle ϕ. For the stable *anti*-structure, the C–F bond is elongated by *ca.* 0.02 Å and the C–N bond shortened by *ca.* 0.03 Å relative to the orthogonal conformation. Moreover, the bond lengths of the *syn*-structure (ϕ = 0) are not very different to those in the *anti*-structure (ϕ = 180°). In other words, the variation in these bond lengths has a predominant twofold *Fourier* component, which can be identified with the stereoelectronic term in the energy decomposition.

Fourier analysis shows that the energy variation in ϕ (*Fig. 1*) is closely represented as the sum of three terms: $E[\text{kcal}\cdot\text{mol}^{-1}] \approx 5.13 + 1.45 \cos \phi - 2.52 \cos 2\phi + 1.16 \cos 3\phi$. One might interpret the threefold term as the net 'steric' contribution favouring staggered conformations, the twofold one as the stereoelectronic term favouring *syn*- and *anti*-planar conformations, while the onefold term differentiates between these two conformations. However, this interpretation is oversimplified, because it ignores the strong coupling between lone-pair orientation (ϕ) and N pyramidality (τ) in this molecule.

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³) Note the analogy with the amide group, where, for the planar structure, both the donor orbital (p_N) and the acceptor orbital (p*(C–O)) are p in character.

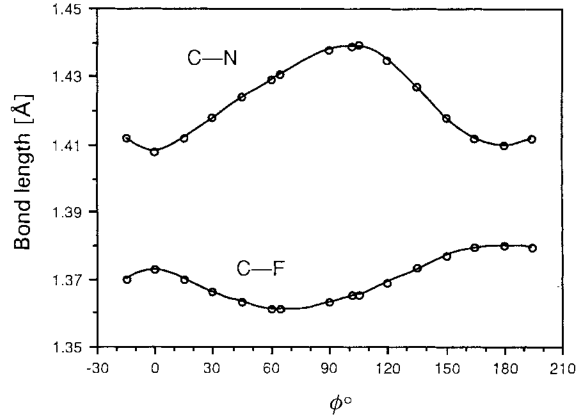

Fig. 3. *C—F and C—N bond lengths as function of torsion angle* ϕ (see *Fig. 2*)

Coupling between Rotation and Nitrogen Inversion. – To follow this coupling, we have mapped the molecular energy $E(\phi, \tau)$ in two dimensions. The symmetry of the map corresponds to one of the 7 frieze groups, described by *Coxeter* as '1½ dimensional' groups (*Fig. 4*) [16]. There are symmetry-equivalent points at (ϕ, τ), $(-\phi, \tau)$, $(180° + \phi, -\tau)$, $(180° - \phi, -\tau)$. Note that inversion at N (change in sign of τ) is equivalent to adding 180° to ϕ. The map (*Fig. 5*) was obtained by 64 point-by-point energy-minimization calculations (*Table 1*), followed by interpolation; as a result, the points do not lie exactly in a plane in the hyperspace but rather in a 'relaxed' plane. To avoid proliferation of symbols to characterize the cardinal conformations, we use the descriptive nomenclature of *Reed* and *Schleyer* [15], as shown in *Fig. 6*. (Note that we use their labels to describe idealized conformations whereas they used them to describe the structures corresponding to nearby energy minima.) There are energy minima at the *anti*-conformer *A-st* ($E = 0$; $\phi = 180°, \tau = +50°$) and the *syn*-conformer *S-ec* ($E = 5.08$ kcal·mol^{-1}; $\phi = 0°, \tau = +35°$), which are connected by saddle points *I* ($E = 5.14$ kcal·mol^{-1}; $\phi = 180°$, $\tau = -23°$) and *P-st* ($E = 7.53$ kcal·mol^{-1}; $\phi = 90°$, $\tau = \pm 54°$). An energy maximum occurs for the planar, perpendicular conformation *P-pl* ($E = 12.14$ kcal·mol^{-1}; $\phi = 90°$, $\tau = 0°$). The dashed curve in *Fig. 5* connects *A-st* to *S-ec via P-st* and corresponds to the path along which the energy was plotted in *Fig. 1*. The first half of this path, from *A-st* to *P-st*, involves essentially pure rotation: τ stays nearly constant. In the second half, however, τ changes significantly. The direct route between *A-st* and *S-ec via AS-pl* and *I* involves pure inversion.

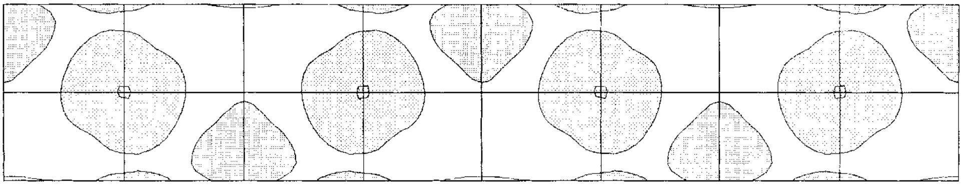

Fig. 4. *A frieze group pattern in* ϕ (horizontal axis) *and* τ (vertical axis, non-periodic)

The small energy difference (0.06 kcal·mol^{-1}) between *S-ec* and the saddle point *I* raises the question whether *S-ec* is a true minimum or not. Two earlier calculations at

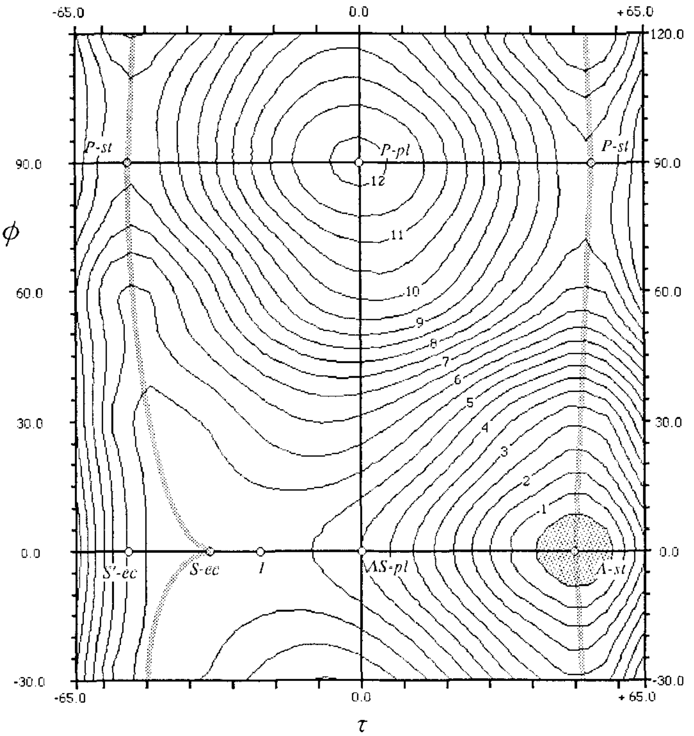

Fig. 5. *Map of the energy function* E (ϕ, τ) *with contours drawn at intervals of 0.5 kcal·mol^{-1}*. Symmetry-equivalent points at (ϕ, τ), $(-\phi, \tau)$, $(180° + \phi, -\tau)$, $(180° - \phi, -\tau)$.

Table 1. *Calculated Energies at Selected Points on the* ϕ, τ *Surface*. The descriptive symbols refer to representative conformations following the nomenclature of *Reed* and *Schleyer* (see *Fig. 6*).

τ	90°	60°	30°	0°
–70	9.78	8.61	9.48	10.51
–54	7.53 (*P-st*)	5.95	5.68	6.06 (*S'-ec*)
–50	7.64	5.96	5.39	5.60
–35	9.18	7.20	5.54	5.08 (*S-ec*)
–30	9.84	7.81	5.79	5.10
–23	10.72	8.64	6.14	5.14 (*I*)
–20	11.05	8.96	6.27	5.14
–10	11.86	9.81	6.53	4.98
0	12.14 (*P-pl*)	10.21	6.42	4.52 (*AS-pl*)
10	11.86	10.10	5.92	3.72
20	11.05	9.51	5.07	2.65
23	10.72	9.25	4.77	2.30
30	9.84	8.56	4.02	1.47
35	9.18	8.04	3.50	0.91
50	7.64	6.93	2.60	0.00 (*A-st*)
54	7.53 (*P-st*)	6.93	2.69	0.09
70	9.78	9.60	5.67	3.06

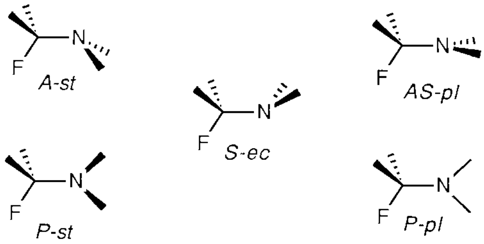

Fig. 6. *Some representative conformations of fluoromethylamine with nomenclature following* Reed *and* Schleyer [15]

different computational levels yielded conflicting answers; those at the 3-21G level [18] indicated that the *syn*-conformation is unstable towards N inversion, whereas at 6-31G* level a stable *syn*-conformer was obtained [15]. New calculations including correlation effects are also ambiguous on this point. At the MP2/6-31G** level *S-ec* appears to be stable (by 0.06 kcal·mol^{-1}), whereas calculations at the corresponding MP3 and MP4 levels failed to converge. The question of the existence and height of the barrier is thus moot. Even if the *syn*-conformation *S-ec* should turn out to be classically stable, it is almost certainly quantum-mechanically unstable in the sense that its first vibrational mode would not be contained in the well.

Coplanar *vs.* Perpendicular Orbital Orientations. – Although a rigourous separation of energy contributions is not possible, the results at our disposal enable us to construct a kind of thermochemical cycle involving structures where one or other kind of contribution can be regarded as being switched on or off. The anomeric effect is zero at $\phi = 90°$ (perpendicular conformations), where the two orbitals involved are orthogonal, and it attains its maximum when they are in the same plane.

Fig. 7 shows the energy difference (ΔE) between perpendicular conformations and those where the lone pair is coplanar with the C—F bond at fixed τ values. It thus portrays how the anomeric effect changes with the direction of the lone pair and the degree of pyramidality at N. For the pyramidal *anti*-structure corresponding to the

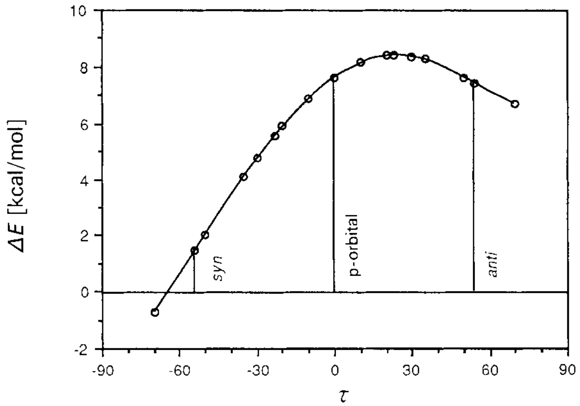

Fig. 7. $\Delta E = E(90°, \tau) - E(0, \tau)$ *is an expression of the anomeric effect.* It gives the energy difference between perpendicular conformations and those where the lone pair is coplanar with the C—F bond for a series of τ values.

global energy minimum, ΔE is 7.5 kcal·mol^{-1}. This can be identified with the magnitude of the *anti* anomeric effect. As the N-atom is made less pyramidal, the inclination of the lone pair to the C–F bond direction changes and the donor orbital acquires more p character. The net result is initially a slight *increase* in the anomeric effect, with a maximum around $\tau = 25°$. Further planarization produces the N-planar structure, which has practically the same ΔE as the *anti*-structure. Here, the anomeric effect can hardly be described as either *anti* or *syn*, since it now involves a p-orbital as donor. In the whole *anti*-region, from *AS-pl* to *A-st*, the magnitude of the anomeric effect, estimated in this way as ΔE, hardly changes. In contrast, pyramidalization towards the *syn*-orientation leads to a rapid decrease in ΔE. For the *syn*-structure with the same pyramidality as the *anti*-structure (*S'-ec*), ΔE is only 1.5 kcal·mol^{-1}. However, this structure can be regarded as being destabilized by repulsive interactions between the two pairs of eclipsed H-atoms. At any rate, as seen in *Fig. 5*, this structure gains 1.0 kcal·mol^{-1} by relaxation to *S-ec* and a further 0.5 kcal·mol^{-1} on further flattening to the N-planar structure *AS-pl* already described. By this criterion, the *syn* anomeric effect can only be a poor substitute for the *anti* one, while the p-orbital anomeric effect is substantial.

Polynomial Curve Fitting. – *Fig. 8* shows the dependence of E on the N pyramidality τ for several values (0, 30, 60, 90°) of the torsion angle ϕ. The coefficients of the power expansions are listed in *Table 2*. In the perpendicular conformations at $\phi = 90°$, where the

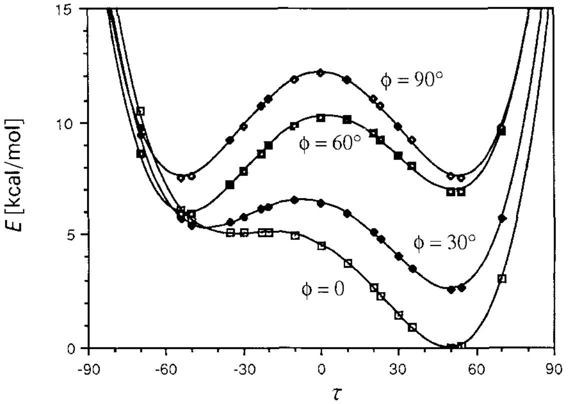

Fig. 8. *Dependence of energy* E *on the pyramidality* τ *at torsion angle values,* $\phi = 0, 30, 60, 90°$

Table 2. *Coefficients of Terms in the Power Series Approximations to the Energy Curves Shown in* Fig. 8. Addition of cubic terms yields only marginal improvement. To keep the coefficients close to the order of magnitude of unity, the curve fitting was made with τ expressed in radians (although in degrees in *Fig. 8*)[a]).

ϕ [°]	τ^0	τ^1	τ^2	τ^4	rms fit[b])
90	12.22	0	–10.48	5.92	0.04
60	10.28	0.53	–9.37	5.74	0.09
30	6.48	–1.60	–7.34	5.41	0.05
0	4.57	–3.20	–6.22	5.16	0.12

[a]) Units for coefficients of τ are kcal, kcal·rad^{-1}, kcal·rad^{-2}, kcal·rad^{-4}, respectively.

[b]) Rms fit is defined as: $[\sum_i (\hat{E}_i - E_i)^2]^{1/2}$ where $\hat{E}_i$ is obtained from the power series fit.

anomeric effect is switched off, the energy dependence on τ is closely fitted by a symmetric double-well quartic function, as found for several other amines with the appropriate symmetry [19]. The energy barrier, $E(P\text{-}pl)-E(P\text{-}st)$ is 4.6 kcal·mol^{-1}. For the non-perpendicular conformations, *syn-* and *anti*-structures with the same ϕ are no longer equivalent; the loss of mirror symmetry of the energy dependence is well expressed by a linear term. Although at $\phi = 0$, 180° the *anti*-structure is much more stable than the *syn*, the order reverses for small deviations from 90°. This is clearly seen in the change of sign of the linear term. *Table 2* shows that the quartic term stays practically constant over the entire ϕ range. *Bürgi* and *Dubler-Steudle* found an analogous constancy of the quartic term in their analysis of experimental data for a series of automerization reactions of (s-*cis*-η^4-butadiene)metallocene complexes [18].

Reaction Coordinates for C–F Bond Breaking. – How does change in the C–F bond distance affect the structure and energy of the fluoromethylamine molecule? Results of calculations for the *anti* (*A-st*) and perpendicular (*P-st*) conformations are listed in *Table 3*. The energy was minimized with respect to all variables except the driving coordinate, the C–F distance, and the conformational constraint for the *P-st* family. At the MP2 level we reoptimized the structures in which the C–F distance was unconstrained and also

Table 3. *Calculated Structural and Energy Parameters for Fixed Values of the C–F Distance.* Energies are in kcal·mol^{-1}, distances in Å, and angles in degrees.

C–F	d_N	d_C	Relative E	τ	C–N
A) *anti*-Conformation ($\phi = 0$)					
HF level					
1.300	0.349	0.411	2.97	50.9	1.422
1.380	0.341	0.381	0.00	49.9	1.410
1.500	0.324	0.337	4.35	47.8	1.392
1.700	0.285	0.265	21.01	42.7	1.361
2.000	0.200	0.158	47.20	30.6	1.319
2.300	0.121	0.066	67.98	18.8	1.292
3.000	0.073	0.008	104.37	11.4	1.271
MP2 level					
1.410	0.361	0.385	0.00	52.2	1.414
2.000	0.229	0.205	41.93	34.6	1.339
2.300	0.160	0.125	65.68	24.3	1.319
3.000	0.079	0.011	108.28	12.1	1.297
B) Perpendicular conformation ($\phi = 90°$)					
HF level					
1.300	0.371	0.382	2.00	54.0	1.445
1.362	0.371	0.359	0.00	54.2	1.438
1.500	0.372	0.310	6.55	54.5	1.427
1.700	0.374	0.242	27.81	55.1	1.414
2.000	0.378	0.150	62.94	56.1	1.397
2.300	0.378	0.078	92.77	56.7	1.385
MP2 level					
1.386	0.403	0.358	57.7	0.0	1.449
2.000	0.408	0.179	59.2	56.2	1.413
2.300	0.410	0.130	59.4	87.2	1.405
3.000	0.410	0.099	58.2	140.4	1.404

several other structures with fixed C—F distances. Stretching of the C—F bond in the *anti* (*A-st*) conformation leads to a decrease in the pyramidality of the N as well as of the C-atom[4]). In the perpendicular *P-st* family of conformations, the pyramidality at C behaves in much the same way as in the *anti* one, but the pyramidality at N stays practically constant as the C—F bond is stretched.

For both families, the energy changes along the reaction coordinate are well represented by *Morse*-type curves (*Fig. 9*). The calculated points for the 6-31G** and MP2 level calculations were fitted by least-squares (*Table 4*). The estimated exponential parameters B and dissociation energies D_e are of the expected order of magnitude[5]), but they should not be taken too seriously, especially the energies, because our calculations

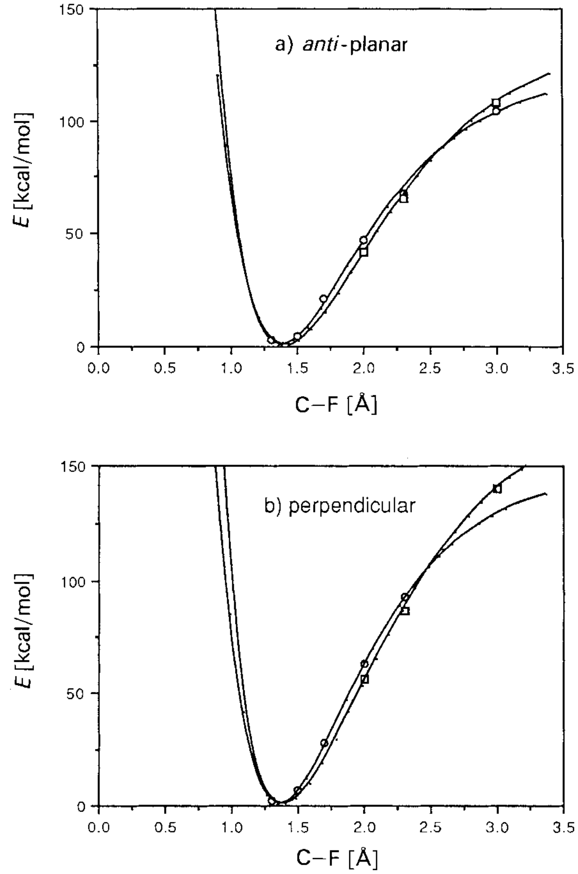

Fig. 9. Morse-*type curves* ($E = D_e[1 - \exp\{-B(r - r_0)\}]^2$) *for the variation in the C—F distance in the* anti-*planar* (a) *and perpendicular* (b) *conformations at both HF* (circles) *and MP2* (squares) *levels*

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[4]) By analogy with *Fig. 2*, the pyramidality at C is defined as the distance of the atom from the plane of its three non-fluorine substituents.

[5]) The dissociation energy of the C—F bond of methylfluoride is *ca.* 110 kcal·mol^{-1} (T. L. Cottrell, 1958, 'The Strengths of Chemical Bonds', 2nd Edition, Butterworths) and B is typically not far from 2 Å^{-1}.

Table 4. *Values of* D_e *and* B *Estimated by Least-Squares Fitting of Calculated Energies to* Morse-*Type Functions* ($E = D_e[1 - \exp\{B(r - r_0)\}]^2$). Standard deviations are in parentheses. N is the number of points used for the calculation.

Fig.	Level	Conformation	D_e [kcal-mol^{-1}]	B [Å^{-1}]	N	r_0 [Å]
a)	MP2	0°	141 (4)	1.31 (4)	4	1.410
b)	HF	0°	123 (4)	1.54 (6)	7	1.380
c)	MP2	90°	182 (3)	1.30 (3)	4	1.386
d)	HF	90°	148 (3)	1.66 (3)	6	1.362

become more and more precarious as the C–F bond is stretched and dissociation is approached. For very large C–F distances, the closed-shell formalism fails to describe the bond-breaking process, involving unpairing of electrons. While we cannot be quite certain about the nature of the dissociation products, it seems likely that these are not the closed-shell species, methyleneiminium cation and fluoride anion, but rather the open shell radicals. The ionization potential of the methyleneamine radical can be expected to be around 10 eV, in any case larger than the electron affinity of a F-atom (3.45 eV). The supposed improvement offered at the MP2 level becomes increasingly irrelevant in this region, because the real deficiency in the model is not its inadequacy to handle correlation, but its inability to describe the radical-like products. There is no problem about calculating the dissociation energies into the closed shell products; at 6-31G** level, they are *ca.* 90 kcal · mol^{-1} larger than the estimated D_e values for the *anti*-structure and *ca.* 135 kcal · mol^{-1} larger for the perpendicular one.

The energy relationships involved in these conformational and dissociative processes are summarized in the thermochemical cycle shown in *Fig. 10*. Whichever way we look at it, the C–F bond appears to be weaker in the *anti*-family than in the perpendicular one. For the ill-defined dissociation products of the HF and MP2 calculations, the difference amounts to some 25–40 kcal · mol^{-1}; for dissociation into the closed shell ions, it is even larger, *ca.* 70 kcal · mol^{-1}. These estimates are all much greater than the rotation barrier in

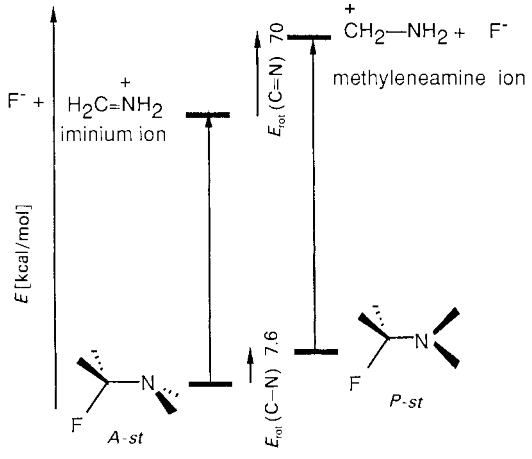

Fig. 10. *Thermochemical cycle for dissociation of fluoromethylamine in* anti-*planar and perpendicular conformations to ionic products.* The energies of the actual products are almost certainly lower.

the neutral fluoromethylamine molecule. The value we choose can be taken as another measure of the anomeric effect and its influence on bond-breaking energies. (In view of the many uncertainties, allowance for zero-point energy would seem to be superfluous at this stage.)

In the unperturbed molecules, the C–F bond is longer in the *anti*-conformation than in the perpendicular one, but only by 0.018 Å (HF) or 0.024 Å (MP2). This is another example of the sharp sensitivity of activation energy of a bond-breaking process to small changes in ground-state geometry that has been discussed in [20].

Is There a *syn* Anomeric Effect and What is it Worth? – There seem to be several criteria for estimating the relative strength of the anomeric effect for different conformations of a molecule like fluoromethylamine: *1*) an energetic criterion – the molecular energy stabilization; *2*) a structural criterion – changes in bond lengths; *3*) another energy criterion – the energy difference between coplanar and perpendicular conformations; *4*) a kinetic criterion – differences in activation or bond-breaking energies. We are interested here mainly in the comparison between the *anti* and the *syn* anomeric effects, operative when the N lone pair is, respectively, in an *anti*- or *syn*-planar orientation to the C–F bond. It is immediately clear that the problem is complicated by the difficulty of separating stereoelectronic effects from other effects that may be operating simultaneously. For example, according to criterion *1*, the *syn*-effect would appear to provide *ca.* 5 kcal·mol^{-1} less stabilization than the *anti*-effect (*Fig. 1*), but a good part of this difference has to be attributed to the effect of the two pairs of eclipsed interactions in the former structure. The severity of these eclipsed interactions can be attenuated by flattening the N pyramid in the *syn*-conformation, but this, in turn, requires the cost of the rehybridization energy. The net result is that on flattening the N pyramid, there is actually a small (0.5 kcal·mol^{-1}) gain in energy. According to criterion *2*, structural expression, the *syn*-effect is quite comparable to the *anti* one. *Fig. 2* shows that the lengthening of the C–F bond is slightly more in the *anti*-planar conformation, while the shortening of the C–N bond is slightly less. According to criterion *3*, the *syn* anomeric effect is a poor substitute for the *anti* one (*Fig. 7*). However, in this comparison, we again neglect the effect of the eclipsed interactions. With τ close to 55°, there are two such interactions in the *syn*-structure, one in the perpendicular structure and none in the *anti*-structure. As with criterion *1*, when allowance is made for this handicap, the difference between the *syn*- and *anti*-structures becomes less pronounced. For the family of structures with planar sp^2-hybridized N, there is no serious eclipsing either in the coplanar (*AS-pl*) or perpendicular (*P-pl*) conformations. For *AS-pl*, the anomeric effect according to *3* is practically equal to that in the staggered *anti*-planar structure *A-st* at the global energy minimum. Paradoxically, according to criterion *4*, the anomeric effect in the *syn*-structure must be greater than in the stable *anti*-structure. Since the *syn*-structure is less stable than the *anti* by *ca.* 5 kcal·mol^{-1} and fissure of the C–F bond leads to the same products in both cases, the bond dissociation energy for the *syn*-structure must be correspondingly *ca.* 5 kcal·mol^{-1} less. For the perpendicular structures the C–F bond dissociation energy is considerably higher (40–70 kcal·mol^{-1}), but here the product is the excited one in which the planes of the CH_2 and NH_2 groups are orthogonal.

Although we may all feel that we understand the anomeric effect, its calibration in terms of observed or calculated quantities is seen to be not free from complications.

Computational Details. – *Ab initio* SCF calculations were done with the program MONSTERGAUSS [10] on an *IBM 3090-300E* computer under VM/CMS. Correlation calculations at MP2, MP3, and MP4 levels were done with the program GAUSSIAN86 [21] on an *IBM 3090* computer under MVS/XA. Ground-state molecular geometries were optimized at the RHF level [22] with the standard 6-31G** basis set by the optimally conditioned (OC) method, except for the transition-state structures [23], which required the use of the VA05AD method. Geometries and energies of selected structures are given in *Table 5.*

Table 5. *Geometries and Energies of Selected Conformations at Different Computational Levels.* Distances in Å, angles in degrees.

anti-Conformer, *A-st*

Level	Energy	C–N	C–F	F–C–N	H–C–N	H–N–C	HCNF	HNCF	τ	d_C	d_N
(7/4/2)[a])	–194.028469	1.427	1.401	112.4	110.3	113.0	118.2	62.4	47.6	0.37	0.32
6-31G**	–194.083631	1.410	1.380	110.0	113.1	112.0	119.4	61.3	49.9	0.38	0.34
MP2	–194.582712	1.414	1.410	113.7	109.6	111.0	119.5	60.2	52.2	0.38	0.36

syn-Conformer, *S-st*

Level	Energy	C–N	C–F	F–C–N	H–C–N	H–N–C	HCNF	HNCF	τ	d_C	d_N
6-31G**	–194.075540	1.408	1.373	111.6	111.5	116.7	118.7	111.0	35.3	0.36	0.24
MP2	–194.573842	1.402	1.410	111.7	111.5	116.5	118.5	111.3	36.1	0.36	0.24

$>C=\overset{+}{N}<$

Level	Energy	C–N	H–C–N	H–N–C
(7/4/2)	-94.280585	1.292	119.3	121.6
6-31G**	-94.394716	1.263	119.8	121.7

$\cdot CH_2NH_2$

Level	Energy	C–N	H–C–N	H–N–C	d_C	d_N
6-31G**	-94.597944	1.400	115.9	113.8	0.23	0.31

$\cdot CH_2NH_2$

Level	Energy	C–N	H–C–N	H–N–C	d_C	d_N
6-31G**	-94.588690	1.418	120.4	111.6	0.01	0.36

[a]) Basis set [13s8p]→(7s4p) + 2d on first-row atoms, [8s]→(5s) + 2p on the H-atom.

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