Enols of Amides. The Effect of Fluorine Substituents in the Ester Groups of Dicarboalkoxyanilidomethanes on the Enol/Amide and *E*-Enol/*Z*-Enol Ratios. A Multinuclei NMR Study[1]

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Condensation of phenyl isocyanate substituted by 4-MeO, 4-Me, 4-H, 4-Br, and 2,4-$(MeO)_2$ with esters $CH_2(CO_2R)CO_2R'$, R = CH_2CF_3, R′ = CH_3, CH_2CF_3, $CH(CF_3)_2$, or R = CH_3, R′ = $CH(CF_3)_2$ gave 17 "amides" $ArNHCOCH(CO_2R)CO_2R'$ containing three, six, or nine fluorines in the ester groups. X-ray crystallography of six of them revealed that compounds with ≥6 fluorine atoms exist in the solid state as the enols of amides $ArNHC(OH)=C(CO_2R)CO_2R'$ whereas the ester with R = R′ = CH_3 was shown previously to have the amide structure. In the solid enols, the OH is cis and hydrogen bonded to the better electron-donating (i.e., with fewer fluorine atoms) ester group. X-ray diffraction could not be obtained for compounds with only three fluorine atoms, i.e., R = CH_2CF_3, R′ = CH_3 but the ^{13}C CP-MAS spectra indicate that they have the amide structure in the solid state, whereas esters with six and nine fluorine atoms display spectra assigned to the enols. The solid enols show unsymmetrical hydrogen bonds and the expected features of push−pull alkenes, e.g., long $C_\alpha=C_\beta$ bonds. The structure in solution depends on the number of fluorine atoms and the solvent, but only slightly on the substituents. The symmetrical systems (R = R′ = CH_2CF_3) show signals for the amide and the enol, but all systems with R ≠ R′ displayed signals for the amide and for two enols, presumably the *E*- and *Z*-isomers. The [Enol I]/[Enol II] ratio is 1.6−2.9 when R = CH_2CF_3, R′ = CH_3, $CH(CF_3)_2$ and 4.5−5.3 when R = CH_3, R′ = $CH(CF_3)_2$. The most abundant enol display a lower field δ(OH) and a higher field δ(NH) and assigned the *E*-structure with a stronger O−H···O=C(OR) hydrogen bond than in the *Z*-isomer. δ(OH) and δ(NH) values are nearly the same for all systems with the same cis CO_2R group. The [Enols]/[Amide] ratio in various solvents follows the order CCl_4 > $CDCl_3$ > CD_3CN > DMSO-d_6. The enols always predominate in CCl_4 and the amide is the exclusive isomer in DMSO-d_6 and the major one in CD_3CN. In $CDCl_3$ the major tautomer depends on the number of fluorines. For example, in $CDCl_3$, for Ar = Ph, the % enol (K_{Enol}) is 35% (0.54) for R = CH_2CF_3, R′ = CH_3, 87% (6.7) for R = R′ = CH_2CF_3, 79% (3.8) for R = CH_3, R′ = $CH(CF_3)_2$ and 100% (≥50) for R = CH_2CF_3, R′ = $CH(CF_3)_2$. ^{17}O and ^{15}N NMR spectra measured for nine of the enols are consistent with the suggested assignments. The data indicate the importance of electron withdrawal at C_β, of intramolecular hydrogen bonding, and of low polarity solvents in stabilizing the enols. The enols of amides should no longer be regarded as esoteric species.

Introduction

Observable enols of amides are so far relatively rare species. Kresge and co-workers generated the short-lived NCC(OH)=C(OH)NHMe by hydration of a ketene and estimated a pK_{Enol} (H_2O) of 12.08,[2a] and they also observed the enol of *N*-methylindolin-2-one.[2b] A species which may be $PhCH=C(OH)NEt_2$ is a short-lived intermediate in the reaction of phenylketene with diethylamine.[2c] Hegarty suggested the formation of a simple enol of amide by solvolysis of an α-chloroenamine,[3a] but this is in contrast with calculations.[3b] Several solid enols of amides appear in the Cambridge Structural Database.[4]

Our recent investigations on enols of amides (**1**), X = NRR′ had shown[5,6] that they may be observable (i.e. pK_{Enol} < 2 and the enol's NMR spectra can be recorded) in two types of systems. (a) Systems carrying bulky aromatic substituents on C_β may show moderate kinetic stability at 0 °C but they isomerize completely to the amide within a few hours.[5] (b) In several systems carrying two β-electron-withdrawing groups (EWGs) the

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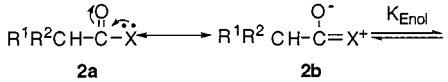
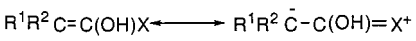
enol is observable, and sometimes it has a comparable or even higher thermodynamic stability than the tautomeric amide.[6] The rationale behind the use of β-EWGs is based on eq 1.



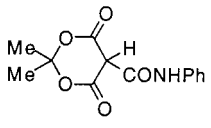
2a **2b** (1)



1a **1b**

The enol of amide, **1a**, X = NRR′ is usually many orders of magnitude less stable than the tautomeric amide, **2a,** X = NRR′[7] due to stabilization of the amide by hybrid **2b**.[8] If enol **1a** can be similarly stabilized, then the equilibrium constant K_{Enol} will increase (and $pK_{Enol} = -\log K_{Enol}$ will decrease). EWGs that can resonatively delocalize the negative charge on C_β of hybrid **1b** will stabilize the enol but destabilize the amide form, e.g., by $R^1/R^2/O^-$ repulsion in **2b**. Moreover, frequently they can stabilize the enol by hydrogen bonding of R^1 or R^2 to the OH group. Consequently, EWGs can be extremely efficient in decreasing pK_{Enol} from the calculated value of 21.3 for the parent acetamide/1-aminoethenol ($R^1 = R^2 = H$)[7a] to a pK_{Enol} value of ca. 0 or lower. Similar stabilization is achieved in the stable enols of β-diketones, e.g., acetylacetone, compared with monoenols, e.g., acetone.[9]

We reported recently two structurally related β,β-diester-substituted systems where the enol was observed but the pK_{Enol}s differ significantly.[6a] The Meldrum's acid tautomeric pair **3/4** exists completely in the solid state and CCl_4 or $CDCl_3$ solution as the enol **4**. For the open chain dicarbomethoxy analogues **5/6**, the solid state is that of the amide whereas in $CDCl_3$ solution it appears mostly as the amide **5** but it also displays a few percent of the enol **6**. The two systems differ in the larger



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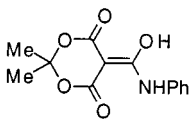
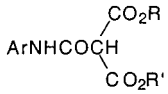


4

$(MeO_2C)_2CHCONHPh$ $(MeO_2C)_2C{=}C(OH)NHPh$

5 **6**

negative charge dispersal ability of the Meldrum's acid moiety than of the open chain analogue. This suggests that by increasing gradually the negative charge delocalizing ability of the ester groups, starting from **5/6**, the relative percentage of the enol should increase, i.e., that pK_{Enol} will decrease gradually. A way to make the ester gradually a more EWG without significantly changing the overall structure is to replace the methyl groups of **5/6** by polyfluoroalkyl groups with increasing number of fluorine substituents. We had chosen to replace one methyl group by one trifluoroethyl (**7c**) or one hexafluoroisopropyl (**7e**) group or the two methyl groups by either two trifluoroethyl groups (**7b**) or by a trifluoroethyl and a hexafluoroisopropyl group (**7d**). The precursor for **7**, R = R′ = CF_3 was not prepared, whereas the precursor for **7**, R = R′ = $CH(CF_3)_2$ was prepared, but it did not form the amide **7a**.



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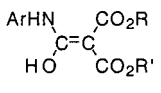

8

a: R = R' = $CH(CF_3)_2$

b: R = R' = CH_2CF_3

c: R = CH_2CF_3; R' = CH_3 (E and Z)

d: R = CH_2CF_3; R' = $CH(CF_3)_2$ (E and Z)

e: R = CH_3; R' = $CH(CF_3)_2$ (E and Z)

These changes lead to systems **7b**−**e** and when R ≠ R′ the possible formation of both *E*- and *Z*- isomers **8c**−**e** and their ratios can be probed. Hydrogen bonding between the OH and a C=O group of a cis ester group was shown to be important in stabilizing the enol[6] and the preference for hydrogen bonding to one ester group over others could be investigated by using the whole set of compounds **5**, **6**, **7b**−**e**, **8b**−**e**.

Two other parameters were also investigated. First, the aryl substituent on the anilino part was changed from an electron-donating to an electron-withdrawing group. Second, the medium was also changed since previous studied showed[6] that the percentage of the amide increases when the solvent becomes more polar and that there are differences between the solid state and solution structure.

Results and Discussion

Synthesis. The amide/enol systems were prepared by a method which previously gave amides/enols.[6,10] The reaction of phenyl isocyanate and its *p*-Br, *p*-Me, *p*-MeO, and 2,4-$(MeO)_2$ derivatives with the dialkyl malonate **9** substituted with three (in one ester group), six (either symmetrically in two ester groups, or in only one ester group), or nine (six in one ester, three in the other) fluorine atoms gave the amido diesters **7b**−**e**, the corresponding enols **8b**−**e** or their mixture **7b**−**e**/**8b**−**e** (eq 2). Ester **9** with R = R′ = CF_3 appears only once in the (patent) literature,[11a] and we did not try to make it. Esters **9b**[11b] and **9c** are known, and esters **9d** and **9e** were prepared by a stepwise esterification of the monohydrogen malonate esters according to the general method of Hauser et al.[12] as demonstrated for **9d** in eq 3. The reaction leading to the nonafluoro diester **9d** from trifluoroethyl hydrogen malonate and hexafluoro-2-propanol leads to some disproportionation which generates few percentage of ester **9b**. Since **9d** decomposes slowly with time, we did not separate it from **9b** and the condensation of eq 2 led to a mixture of mainly **7d**/**8d** containing a few

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(8) For reviews with references up to 1996, see: (a) Hegarty, A. F.; O'Neill, P. In *The Chemistry of Enols*, Rappoport, Z., Ed.; Wiley: Chichester, 1990; Chapter 10, p 639. (b) Kresge, A. J. *Chem. Soc. Rev.* **1996**, *25*, 275.

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(12) Breslow, D. S.; Baumgartner, E.; Hauser, C. R. *J. Am. Chem. Soc.* **1944**, *66*, 1286.

$$CH_2(CO_2R)CO_2R' + ArNCO \xrightarrow{Et_3N} ArNHCOCH(CO_2R)CO_2R' \quad (2)$$

9 **7**

and / or $ArNHC(OH)=C(CO_2R)CO_2R'$

8

a: R = R' = $CH(CF_3)_2$

b: R = R' = CH_2CF_3

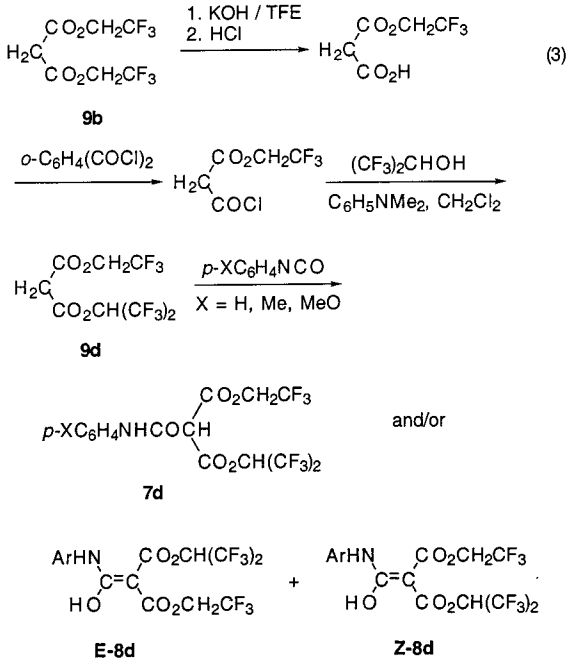
c: R = CH_2CF_3; R' = CH_3

d: R = CH_2CF_3; R' = $CH(CF_3)_2$

e: R = CH_3; R' = $CH(CF_3)_2$

Ar = H, *p*-Me, *p*-MeO (for **9b-e**); *p*-Br (for **9b, 9c, 9e**); 2,4-$(MeO)_2$ (for **9b, 9c**)

percent of **7b/8b**. Sometimes this complicated the analysis of the spectra of **7d/8d** in solution.



Attempted condensation of ester **9a** with phenyl isocyanate did not give the anilido diester **7a**/**8a** but only diphenylurea. A precedent for such reaction is known.[10,13]

These reactions gave altogether 17 anilido diesters systems since the *p*-bromo derivative of **7d/8d** was unstable and the 2,4-dimethoxy derivative was prepared only in the **7b/8b**, **7c/8c** systems. As shown below all systems showed in CCl_4 and $CDCl_3$ solution the presence of the enols **8**.

Solid-State Structures. We have determined by X-ray diffraction the solid-state structures of six of the **7/8** systems which belong to three subgroups. These include (i) two symmetrical systems (**7b/8b**) with two trifluoroethyl groups, with N-Ph and N-*p*-tolyl (*p*-Tol), (ii) three nonsymmetrical hexafluoro derivatives (**7e/8e**) with N-Ph, N-*p*-Tol, and N-*p*-methoxyphenyl (*p*-anisyl, *p*-An), and (iii) one nonafluoro (**7d/8d**) system, with N-*p*-An. Together with the solid-state structure of **5**, we have representatives of four subgroups having zero, six, six, and nine fluorine atoms. Only with the methyl trifluoroethyl subgroup **7c/8c** were we so far unsuccessful in obtaining suitable crystals for determining the solid-state structure, but the solid-state ^{13}C NMR spectra gives alternative strong structural evidence in this case (see below).

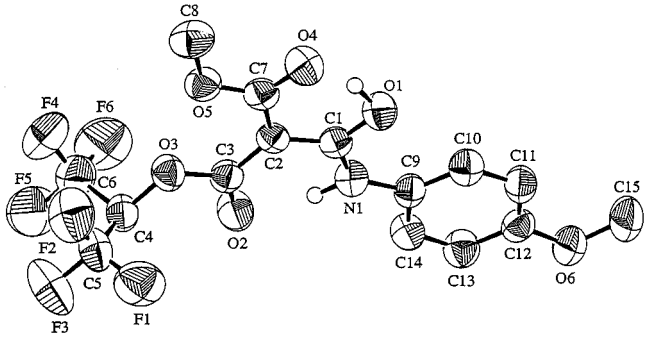


Figure 1. ORTEP drawing of *E*-**8e**, Ar = *p*-$MeOC_6H_4$, with thermal ellipsoids shown at 50% probability. Most hydrogen atoms were omitted for clarity.

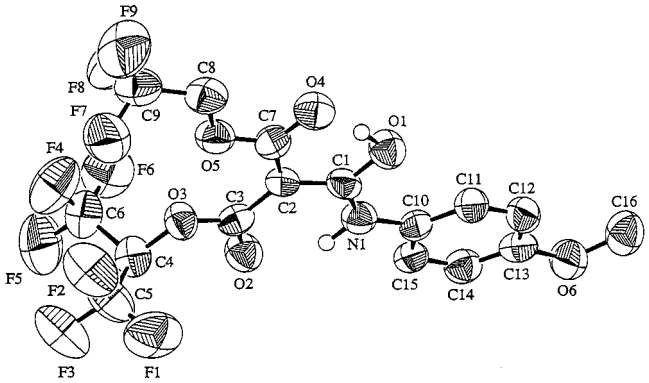


Figure 2. ORTEP drawing of *E*-**8d**, Ar = *p*-$MeOC_6H_4$, with thermal ellipsoids shown at 50% probability. Most hydrogen atoms were omitted for clarity.

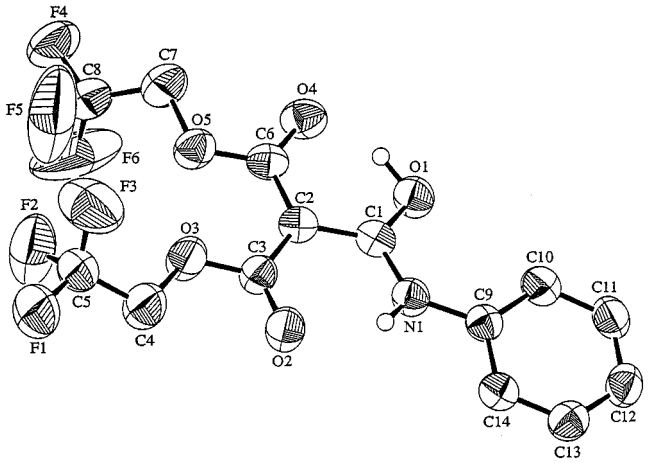


Figure 3. ORTEP drawing of **8b**, Ar = Ph with thermal ellipsoids shown at 50% probability. Most hydrogen atoms were omitted for clarity.

In contrast with the amide structure of the dicarbomethoxy ester **5** (zero fluorine atoms) in the solid state,[6a] all the six *solid* hexa- and nonafluoro-substituted esters have structures of the corresponding enols **8**. This is shown in the ORTEP structures of **8e**, Ar = *p*-An, **8d**, Ar = *p*-An and **8b**, Ar = Ph given in Figures 1−3 which

(13) Arnold, R. G.; Nelson, J. A.; Verbang, J. J. *Chem. Rev.* **1957**, *57*, 47.

Table 1. Selected X-ray Data for $(CF_3)_2CHOCOC(CO_2Me)$=C(OH)NHAr (8e, Ar = Ph, *p*-Tol, *p*-An) at Room Temperature

	length, Å				deg		
bond	Ar = *p*-An	Ar = *p*-Tol	Ar = Ph	angle	Ar = *p*-An	Ar = *p*-Tol	Ar = Ph
C(1)−C(2)	1.425 (5)	1.430 (4)	1.424 (4)	O(1)−C(1)−N(1)	117.4 (3)	117.8 (3)	117.2 (3)
C(1)−N(1)	1.333 (5)	1.321 (4)	1.329 (4)	O(1)−C(1)−C(2)	120.8 (3)	117.8 (3)	120.9 (3)
C(1)−O(1)	1.300 (4)	1.298 (3)	1.307 (3)	N(1)−C(1)−C(2)	121.8 (3)	121.6 (2)	121.9 (3)
C(2)−C(3)	1.428 (5)	1.432 (4)	1.421 (4)	C(1)−C(2)−C(7)	115.9 (3)	115.7 (5)	116.0 (3)
C(2)−C(7)	1.448 (5)	1.440 (4)	1.450 (4)	C(1)−C(2)−C(3)	118.5 (3)	118.8 (2)	119.0 (3)
C(3)−O(2)	1.218 (5)	1.215 (3)	1.223 (4)	C(2)−C(7)−O(4)	122.3 (4)	122.9 (3)	122.1 (3)
C(3)−O(3)	1.374 (5)	1.364 (3)	1.370 (4)	C(2)−C(3)−O(2)	125.8 (3)	126.9 (3)	126.5 (3)
C(4)−O(3)	1.402 (4)	1.405 (3)	1.403 (4)	C(2)−C(7)−O(5)	117.4 (3)	118.0 (3)	117.7 (3)
C(8)−O(5)	1.450 (5)	1.437 (4)	1.450 (4)	C(3)−C(2)−C(7)	125.6 (3)	125.5 (3)	125.0 (3)
C(7)−O(4)	1.238 (5)	1.248 (3)	1.239 (3)	O(2)−C(3)−O(3)	119.0 (3)	118.9 (2)	118.6 (3)
C(7)−O(5)	1.311 (5)	1.309 (4)	1.312 (4)	O(4)−C(7)−O(5)	120.4 (4)	119.0 (3)	120.2 (3)
				O(1)−C(1)−N(1)/C(2)−C(3)−C(7)	3.9	2.2	1.9
				O(1)−C(1)−N(1)/O(1)−C(1)−H(1)	1.9	3.9	0.4
				O(2)−C(2)−C(3)/C(2)−C(3)−C(7)	5.5	3.1	4.7
				O(4)−C(2)−C(7)/C(2)−C(3)−C(7)	6.6	2.4	2.1

Table 2. Selected X-ray Data for *E*-8d, Ar = *p*-An

bond	length, Å	angle	deg
O(1)−C(1)	1.301 (7)	O(1)−C(1)−N(1)	116.9 (6)
O(2)−C(3)	1.238 (7)	O(1)−C(1)−C(2)	120.5 (3)
O(4)−C(7)	1.235 (7)	N(1)−C(1)−C(2)	122.5 (6)
C(2)−C(7)	1.440 (9)	C(1)−C(2)−C(7)	116.2 (6)
C(2)−C(3)	1.417 (9)	C(1)−C(2)−C(3)	119.6 (6)
C(7)−O(5)	1.326 (8)	C(3)−C(2)−C(7)	124.2 (6)
C(3)−O(3)	1.346 (8)	O(2)−C(3)−C(2)	124.4 (6)
C(1)−C(2)	1.427 (9)	O(4)−C(7)−C(2)	123.4 (6)
C(1)−N(1)	1.301 (8)	O(4)−C(7)−C(2)	123.4 (6)
C(10)−N(1)	1.432 (8)	C(1)−N(1)−C(10)	132.2 (6)
		O(1)−H(1)−C(1)/C(2)−C(3)−C(7)	0.34
		O(1)−N(1)−C(1)/N(1)−C(1)−C(10)	0.71
		O(1)−N(1)−C(1)/O(1)−C(1)−H1	0.48
		O(1)−N(1)−C(1)/C(2)−C(3)−C(7)	173.3
		O(2)−O(3)−C(3)/C(2)−C(3)−C(7)	4.1

are representatives of three groups and in Figures S2, S4, and S8 in the Supporting Information which give the ORTEPs for the other three compounds. Selected bond lengths and bond angles are given in Tables 1−3. Table 4 gives data related to hydrogen bonding, i.e., O−H and N−H distances and C=O···H−O, C=O···H−N, O···O, and N···O nonbonded distances.

The stereoviews of the six aryl-substituted compounds are given in Figures S1, S3, S5−S7, and S9 and the general crystallographic information, all bond lengths and angles, positional and thermal parameters are given in Tables S1−S30 of the Supporting Information.

The missing structural data for the 3-fluorine-containing systems are given by the solid ^{13}C NMR spectra for four such systems which show that all have the amide structure **7b** in the solid state (see below). Consequently, for the *N*-aryl-substituted dicarboalkoxyanilidomethanes, the solid-state structure changes regularly with the number of fluorine atoms. It is an amide for compounds with zero (**5**) or three (**7c**) fluorine atoms, but it is an enol for compounds carrying six (**8c** and **8e**) or nine (**8d**) fluorine atoms (Table 5). This result increases significantly the number of known solid-state structures of enols of amides if hydroxy heteroaromatic systems are excluded.

In systems **8d** and **8e** which have two different ester groups, the ester with the lower number of fluorine atoms is consistently at a cis position to the hydroxy group. It is either the $CO_2CH_2CF_3$ group or the CO_2CH_3 group when the other ester group is $CO_2CH(CF_3)_2$. This preference is ascribed to hydrogen bonding, which we suggest to be a dominant factor in determining the configuration of the enol. The oxygen−oxygen distances are shorter than the oxygen−nitrogen distances (Table 4) so that the O···HO hydrogen bond is stronger than the O···NHAr hydrogen bond. The carbonyl of the ester cis to the OH (or the NH) serves as a hydrogen bond acceptor, i.e., a base, and it is a better acceptor when the alkoxy group is a better electron donor. Consequently, the larger the number of electron-withdrawing fluorine atoms on the alkoxy group, the weaker the base, when the hydrogen bond acceptor is the carbonyl. In a competition between two ester groups the one with the fewer fluorine atoms should therefore be preferred in the hydrogen bond to the OH, and it will be cis to it, as was indeed observed.

The solid-state X-ray diffraction of the enol **8b**, Ar = Ph was also determined at 136 K by Prof. Kaftory's group in the Technion, Haifa.[14] The *R* value of 0.048 is much better than that of 0.089 at room temperature. Two crystallographically different molecules which differ significantly in several bond lengths were found in the unit cell. Differences in bond lengths and angles between 136 K and room temperature are not large except for a few C−O bonds of the esters. At 136 K the O−H and N−H bond lengths are 0.84 and 0.88 Å, respectively, and the hydrogens were located at the low temperature. The OHO angles are 149.6°, 149.7°, the OHN angles are 139.8° and 140.8°, and the nonbonded distances are O···O: 2.434 (7), 2.443 Å, N···O: 2.596 (8), 2.616 (9) Å, C=O···HO: 1.672, 1.681 Å, C=O···HN: 1.861, 1.875 Å. These values resemble those at room temperature.

Solid-State Characteristics of the Enols. The availability of six solid-state enol structures enables comparisons of characteristic features, especially the push−pull nature in the zwitterionic enols. The following are the characteristic features: (a) The hydroxy oxygen−cis ester carbonyl oxygen O···O nonbonding distances (Table 4) are all short and nearly similar, ranging from 2.413 (4) Å for **8e**, Ar = *p*-An, to 2.440 (4) Å for **8c**, Ar = *p*-Tol. If small differences are meaningful, the distances are shorter for the three enols **8e** (Ar = Ph, *p*-Tol, *p*-An) (2.413 (4) −2.420 (4) Å) than for the more fluorinated **8b** (Ar = Ph, *p*-Tol) or **8d** (Ar = *p*-Tol) (2.435 (6) −2.440 (4) Å). The changes in the nonbonding N···O=C distances resemble those for the O···O distances, but the distances are significantly larger (2.589 (4) − 2.622 (3) Å) and both extreme values are for the **8e** system. (b) Consistently, the C1−C2 double bond lengths are very long for a double bond, being 1.424 (4) − 1.438 (6) Å. They reflect the partial single bond character in the push−pull system

(14) M. Kaftory, unpublished results

Table 3. Selected X-ray Data for the Enols $(CF_3CH_2OCO)_2C{=}C(OH)NHAr$, 8b, Ar = Ph, *p*-Tol, at Room Temperature

	length, Å			deg	
bond	Ar = Ph	Ar = *p*-Tol	angle	Ar = Ph	Ar = *p*-Tol
C(1)−C(2)	1.438 (6)	1.430 (6)	O(1)C(1)C(2)	122.1 (4)	121.3 (4)
C(1)−O(1)	1.285 (5)	1.285 (4)	O(1)C(1)N(1)	117.0 (4)	116.0 (4)
C(1)−N(1)	1.334 (6)	1.322 (5)	C(1)C(2)C(3)	119.2 (4)	118.2 (4)
C(2)−C(3)	1.432 (6)	1.458 (5)	C(1)C(2)C(6)	114.8 (4)	116.0 (3)
C(2)−C(6)	1.427 (2)	1.421 (6)	N(1)C(1)C(2)	120.9 (4)	122.8 (4)
C(3)−O(2)	1.227 (5)	1.210 (5)	C(3)C(2)C(6)	125.9 (4)	125.8 (4)
C(6)−O(4)	1.236 (5)	1.238 (5)	C(2)C(6)O(4)	124.1 (5)	123.7 (4)
C(3)−O(3)	1.330 (6)	1.346 (5)	C(2)C(3)O(2)	125.6 (4)	125.2 (4)
C(6)−O(5)	1.332 (6)	1.334 (5)	C(2)C(6)O(5)	116.8 (4)	118.1 (3)
C(4)−O(3)	1.425 (6)	1.429 (5)	C(2)C(3)O(3)	115.2 (4)	121.0 (4)
C(4)−C(5)	1.403 (8)	1.477 (8)	C(1)N(1)C(9)	131.4 (4)	130.4 (4)
C(7)−O(5)	1.418 (6)	1.421 (5)	O(1)N(1)C(1)/C(2)C(3)C(6)	3.61	3.0
C(7)−C(8)	1.329 (9)	1.504 (7)	O(2)C(3)C(2)/C(2)C(3)C(6)	0.97	1.4
C(9)−N(1)	1.408 (6)	1.424 (5)	O(4)C(6)C(2)/C(2)C(3)C(6)	0.14	2.2
			C(2)C(3)O(3)/C(2)C(3)C(6)	1.52	1.4
			O(1)N(1)C(1)/C(1)N(1)C(9)	3.5	3.0

Table 4. Parameters for the H-Bonded Moieties of the Solid-State Enols $p\text{-}XC_6H_4NHC(OH){=}C(CO_2R)CO_2R'$

X	R	R'	O···O, Å	N···O, Å	O−H, Å	N−H, Å	C=O···HO, Å	C=O···HN, Å	OHO, deg	NHO, deg
H	CH_2CF_3	CH_2CF_3	2.435 (6)	2.600 (5)	0.95	0.84	1.54	1.90	155	139.9
Me	CH_2CF_3	CH_2CF_3	2.440 (4)	2.613 (5)	1.16	1.03	1.37	1.82	149.4	131
H	Me	$CH(CF_3)_2$	2.416 (3)	2.615 (3)	0.95	1.04	1.50	1.81	162.5	130.7
Me	Me	$CH(CF_3)_2$	2.420 (4)	2.589 (4)	0.94	0.95	1.55	1.797	151.7	143.78
MeO	Me	$CH(CF_3)_2$	2.413 (4)	2.622 (3)	1.07	0.96	1.34	1.76	157.8	142.2
Me	CH_2CF_3	$CH(CF_3)_2$	2.435 (6)	2.605 (7)	0.94	0.94	1.49	1.83	172.4	138.5

Table 5. Structure of the Solid Tautomer of $ArNHCOCH(CO_2R)CO_2R'$

R	R'	no. of F	structure	from
Me	Me	0	amide	X-ray[a]
Me	CH_2CF_3	3	amide	^{13}C solid CP-MAS
Me	$CH(CF_3)_2$	6	enol	X-ray
CH_2CF_3	CH_2CF_3	6	enol	X-ray
CH_2CF_3	$CH(CF_3)_2$	9	enol	X-ray

[a] From ref 6a.

(cf. hybrid **1b**). Similar long C1−C2 bonds were found for previously investigated enols.[6] Within the subfamily **8e**, there is no systematic change in the length for Ar = Ph, *p*-Tol, and *p*-An. The longer value is for **8b**, Ar = Ph. (c) The C_α−O bond lengths of 1.285 (5)−1.315 (4) Å are much longer than the value of 1.23 Å reported for a carbonyl of an amide[15] (e.g., 1.216 Å in **5**). These values are significantly shorter than the C−O bond lengths of 1.413−1.440 Å in alcohols or in enols (1.333 Å),[15] indicating a bond order larger than one (cf. **1b**). Similarly, the C−N bond lengths of 1.301 (8)−1.334 (6) Å are shorter than the =C−N single bond of 1.33−1.35 Å in enamines,[15] indicating again the expected double bond character. (d) The two $=C_\beta-C{=}O$ bonds lengths of 1.417 (9)−1.448 (5) Å are somewhat shorter than the values for single bonds between two sp^2-hybridized carbons (1.46−1.48 Å), indicating some double bond character as expected if the negative charge on **1b** is partially delocalized on the C=O groups. The two bond lengths are not identical but there is no consistent trend concerning which one of them is longer. (e) Except for **8d**, Ar = *p*-An, where the two ester carbonyl bond lengths are nearly the same, the C=O bond of the group hydrogen bonded to the OH is 0.01−0.03 Å longer (at 1.236−1.248 Å) than the C=O bond cis to the NH (1.210−1.238 Å). (f) The aryl group and the double bond are nearly coplanar with an Ar/C=C dihedral angle of <12.5°. (g) The C=O bond lengths are significantly longer than those in normal esters (e.g., 1.175 Å for **5**), as expected (cf. **1b**). The longer bond for the C=O cis to the OH is consistent with the stronger hydrogen bond to the OH than to the NHPh. (h) The bond angle O1C1N1 of 116.0−117.8° between the smaller substituents is smaller than the $(O{=})CC_\beta C(=O)$ bond angle of 124.2−125.9°. (i) All the enols are nearly planar, and the β-substituents are nearly fully conjugated with the C=C bond.

Solid-State CP-MAS ^{13}C NMR Spectra. The solid state X-ray structures are unequivocal but are not necessarily identical with those in solution where several structures should be considered. The solid-state and solution data are linked by the solid-state CP-MAS ^{13}C NMR spectra. We obtained CP-MAS ^{13}C NMR spectra in several cases where the solid structure is known (Table 6) and compared it with the ^{13}C NMR spectra in solution. If both spectra are similar, the structures in solution and in the solid are assumed to be identical, and such identity strengthens the structural assignment.

The solid-state CP-MAS ^{13}C NMR signals for four **7b**/**8b** and four **7c**/**8c** derivatives are given in Table 6, and the observed $\delta(^{13}C)$ values of C_α, C_β and the C=O groups in CCl_4 and DMSO-d_6 solutions are given for comparison. The two systems show characteristic differences in two regions. For **7b**/**8b** there are signals at δ 74.2−75.6 and none at 19.3−60.6 ppm. For **7c**/**8c** there are signals at 51.8−53.8 ppm and none at 62−117.7 ppm. In the low field region **7b**/**8b** display signals at δ 166.5−172.1 and none down to 135.6 ppm. In DMSO-d_6 solution where only the amides are present (see below), there are amide CH signals at 51.8−53.1 ppm and C=O signals at 159.3−164.9 with none at a lower field. In CCl_4 where the enols are the major species the C_β signals are at δ 74.9−75.4 and C=O and C_α signals at 166.5−172.5 ppm. For C_β, C_α, and COO of the enols, the differences $\Delta\delta = \delta(CCl_4) - \delta$(solid state) are 0.8 to −0.4, 0.2−2.6, and 0.1−1.0, respectively, and for C_α of the amides, $\Delta\delta$ = 0 to −1.2 ppm (the assignments of the C=O signals are not always

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Table 6. ^{13}C CP-MAS Chemical Shifts (in bold), in CCl_4 Solution (round parenthesis) and in DMSO-d_6 Solution (square parenthesis) for *p*-$XC_6H_4NHCOCH(COOR)COOCH_2CF_3$/*p*-$XC_6H_4NH(HO)C{=}C(COOR)COOCH_2CF_3$ systems[a,b]

			shifts, ppm							
system	X	R	CH or C_β=	Me	CH_2CF_3	CF_3	Ar	X	COO	C_α or CON
7b/8b	H	CH_2CF_3	**75.6**		**60.6**	**123.1**	**118.3, 120.6, 128.1, 135.6**		**166.9, 171.5**	**169.8**
			(75.2)						(167.3, 172.5)	(171.1)
			[58.7]						[162.9]	[159.7]
	MeO	CH_2CF_3	**74.8**		**61.1 (b)**	**123.0 (sh)**	**117.4, 118.9, 121.2, 129.1**	**53.1**	**166.8, 172.1**	**168.1**
			(74.9)						(167.2, 172.4)	(170.7)
			[58.7]						[163.0]	[159.3]
	Me	CH_2CF_3	**74.2**		**62.8 (b)**	**122.3 (b)**	**131.5, 135.5**	**19.3**	**166.5, 171.5**	**170.1**
			(75.0)						(167.2, 172.4)	(170.8)
			[58.7]						[163.0]	[159.4]
	Br	CH_2CF_3	**75.3**		**61−62 (vb)**	**121.8 (b)**	**132−134 (b)**		**167.1, 172.0**	**170.9 (sh)**
			(75.4)						(167.2, 172.5)	(171.1)
			[58.9]						[162.9]	[160.0]
7c/8c	H	Me	−	**53.1**	**60.4**	−	**124.8, 135.9**		**165.8**	**164.4**
			(75.4, 75.6, 58.6)[c]						(167.5, 174.5, 169.2, 172.6, 162.9, 165.4)[c]	(171.4, 171.0, 159.2)[c]
			[59.2]						[163.4, 164.6]	[160.3]
	MeO	Me	−	**53.1**	**60.3 (sl b)**	−	**119.0−122.2 (b), 131.1**	**53.8**	**163.1, 164.2**	**156.8**
			(75.1, 75.4, 58.9)[c]						(167.4, 174.7, 169.2, 172.5, 163.6, 165.7)[c]	(172.5, 170.7, 157.9)[c]
			[59.2]						[163.6, 164.8]	[160.0]
	Me	Me	−	**52.1**	**58.5**	−	**119.3, 128.9, 134.6, 136.8**	**19.3**	**163.5, 165.3**	**161.7**
			(75.2, 75.6, 58.5)[c]						(167.4, 174.8, 169.2, 172.6, 163.5, 165.6)[c]	(171.2, 170.8, 158.1)[c]
			[59.2]						[163.5, 164.7]	[160.1]
	Br	Me	−	**51.8**	**58−62 (b)**	−	**117.7, 121.5 (b), 131.2 (sl b), 137.7**		**164.3**	**162.9 (sl b)**
			(75.5, 76.0, 58.4)[c]						(167.5, 174.9, 169.2, 172.7, 163.4, 165.7)[c]	(172.7, 171.1, 158.1)[c]
			[59.2]						[163.3, 164.5]	[160.6]

[a] Only values for C_α, C_β and, C=O in solution are given, others are given in Table S35. [b] b = broad, sh = shoulder, sl b = slightly broad, vb = very broad. [c] Signals for both the amides and two enol species.

unequivocal). The signals of enol **5** in $CDCl_3$ at 74.2 and 172.1 ppm (solid) and 75.2 and 171.0 ppm (CCl_4) [6a] fit the above assignments.

We conclude from the good agreement between the δ values in the solid state and in CCl_4 solution, that systems **c** are present in the solid as the amide **7c** (Tables 5 and 6). In contrast, the low field signals in solution for systems **b**, **d**, and **e** (Table 6) are assigned to both the enols and the amides, and we conclude that both species are present.

Structure in Solution. The species present and the compositions of the enol/amide systems in solutions were probed by multinuclei (^{1}H, ^{13}C, ^{19}F, ^{15}N, and ^{17}O) NMR spectra. Quantitative data were obtained from the ^{1}H and ^{19}F spectra and the other spectra served for a qualitative structural analysis. The product distributions were systematically dependent on the solvent and the activating ester groups. The effect of the nitrogen substituents was small and a temperature dependence was found in the few cases investigated.

The product distributions in solution were deduced for each compound/solvent combination by integration of several appropriate signals, both in the ^{1}H and the ^{19}F spectra. The derived product distributions and calculated K_{Enol} values for each compound/solvent are given in four tables. The data in Table 7 exemplify similarities and differences between the different methods for the five derivatives of **7c/8c** in four solvents. Similar data for **7b/8b**, **7d/8d**, **7e/8e** are given in Tables S31−S33 of the Supporting Information. Small unidentified and decomposition signals are not given. The detailed ^{1}H, ^{19}F, and ^{13}C spectra of all compounds in all solvents are given in Supplementary Tables S34−S36 in the Supporting Information.

A summary of the product distributions of all the systems in all solvents studied is given in Table 8. Table 9 gives the corresponding ratios of the two enols (see below) and the K_{Enol} values derived from the data in Table 8.

^{1}H NMR. All the systems investigated show in CCl_4, $CDCl_3$, CCl_4−$CDCl_3$ mixtures, $Cl_2CDCDCl_2$ (and for single system in THF-d_8 and C_6D_6) signals at $\delta > 15$ ppm in the ^{1}H NMR spectrum, indicating the presence of hydrogen-bonded enols.[16] In contrast with the single enol observed for **4**, all the nonsymmetrical systems **7c−e/8c−e** show five signals at δ values > 8 ppm which were identified as belonging to three species, two enols and an amide. Consistently, the lowest field signal in $CDCl_3$ at δ 15.9−17.3 was accompanied by a signal at δ 11.1−11.5 ppm, having the same integration. These two signals were ascribed, respectively, to the OH and NH signals

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Table 7. Composition of *p*-$XC_6H_4NHCOCH(CO_2Me)CO_2CH_2CF_3$ and Its Enols (7c/8c) in Several Solvents at Room Temperature

X	solvent	method (signal integrated)	% amide	% Enol I	% Enol II	Enol I/Enol II	K_{Enol}[a]
Br	CCl_4	^{1}H NMR (NH, OH)	30	50	20	2.5	2.3
		^{1}H NMR (Me)	32	46	22	2.1	2.1
		^{19}F NMR	28	52	20	2.6	2.6
	$CDCl_3$	^{1}H NMR (NH, OH)	71	20.5	8.5	2.4	0.41
		^{19}F NMR	70	17.5	12.5	1.4	0.43
	CD_3CN	^{1}H NMR (NH)	100				≤0.02
		^{1}H NMR (Me)	100				≤0.02
		^{19}F NMR	100				≤0.02
	DMSO-d_6	^{1}H NMR (NH)	100				≤0.02
		^{1}H NMR (CH)	100				≤0.02
		^{19}F NMR	100				≤0.02
H	CCl_4	^{1}H NMR (OH, NH)	28	53	19	2.8	2.6
		^{19}F NMR	31.5	49	19.5	2.5	2.2
	$CDCl_3$	^{1}H NMR (NH)	77	17	6	2.8	0.3
		^{1}H NMR (MeO)	76	18	6	3.0	0.3
		^{19}F NMR	69	21	10	2.1	0.4
	CD_3CN	^{1}H NMR (NH)	100				≤0.02
		^{19}F NMR	100				≤0.02
	DMSO-d_6	^{1}H NMR (NH)	100				≤0.02
		^{19}F NMR	100				≤0.02
p-Me	CCl_4	^{1}H NMR (NH, OH)	23	55	22	2.5	3.3
		^{19}F NMR	24	52	24	2.2	3.2
	$CDCl_3$	^{1}H NMR (NH, OH)	69	22	9	2.4	0.45
		^{1}H NMR (Ar)	59	26	15	1.7	0.69
		^{19}F	68	22	10	2.2	0.47
	1:9 $CDCl_3$−CCl_4	^{1}H NMR	24	54	22	2.4	3.2
		^{19}F NMR	23	54	23	2.3	3.3
	1:4 $CDCl_3$−CCl_4	^{1}H NMR (NH)	28	51	20	2.6	2.5
	CD_3CN	^{1}H NMR (NH)	100				≤0.02
		^{19}F NMR	100				≤0.02
	DMSO-d_6	^{1}H NMR	100				≤0.02
		^{19}F NMR	100				≤0.02
p-MeO	CCl_4	^{1}H NMR (NH, OH)	22	56	22	2.5	3.5
		^{1}H NMR (OH, CH)	24	52	24	2.2	3.2
		^{19}F NMR	21	56	23	2.4	3.8
	$CDCl_3$	^{1}H NMR (NH, OH)	68	22	10	2.2	0.47
		^{1}H NMR (Me)	64	25	11	2.3	0.56
		^{1}H NMR (Ar)	66				
		^{19}F NMR	67	23	10	2.3	0.49
	CD_3CN	^{1}H NMR (OH)	100				≤0.02
		^{19}F NMR	100				≤0.02
	DMSO-d_6	^{1}H NMR (NH)	100				≤0.02
		^{19}F NMR	100				≤0.02
	C_6D_6	^{1}H NMR (NH)	64	26	10	2.6	0.56
		^{19}F NMR	62	26	12	2.2	0.61
2,4-$(MeO)_2$	CCl_4	^{1}H NMR (NH, OH)	19	60	21	2.9	4.3
		^{1}H NMR (Ar)	19	58	23	2.5	4.3
		^{1}H NMR (OMe)	18	62	20	3.1	4.6
	$CDCl_3$	^{1}H NMR (OH, NH)	72	20	8	2.5	0.39
		^{1}H NMR (Ar)	71	21	8	2.6	0.41
		^{1}H NMR (MeO)	70	23	7	3.3	0.42
	CD_3CN	^{1}H NMR (NH)	100				≤0.02
		^{19}F NMR	100				≤0.02
	DMSO-d_6	^{1}H NMR (NH)	100				≤0.02
		^{19}F NMR	100				≤0.02

[a] K_{Enol} = ([Enol I] + [Enol II])/[Amide].

of the main enol, which we presently term "enol I". Between these two signals there are two other signals: one at δ 15.1−16.1 and one at δ 11.6−12.1, of identical intensities, but smaller than those of enol I. These are ascribed, respectively, to the OH and NH signals of another enol, which we term "enol II". The fifth and highest field signal is assigned to the NH group of the amide of tautomer **7**. The equilibria between the three species were established immediately on dissolution. Remarkably and luckily for our analysis the relative integrations of the five signals either among themselves or in comparison with other signals (see below) were reproducible within the expected integration error, in contrast with the frequent behavior of OH (and NH) signals. The ^{1}H NMR spectrum of **7c/8c** (Ar = *p*-BrC_6H_4) in CCl_4 given in Figure 4 and in Figure S10 in $CDCl_3$ are typical for the low field region of **7c**−**e/8c**−**e** and for the difference between the two solvents (see below). The effect of the number of fluorine atoms is shown by the nearly complete absence of the amide in a more fluorinated system **8e**, Ar = *p*-An (Figure S11). Evidence for the nature of these signals, in addition to their position, is that on shaking with a D_2O solution, the two signals ascribed to the OH groups are exchanged immediately, whereas the signals ascribed to the NH groups exchange more slowly.

Table 8. *E*-8/*Z*-8/7 Distributions in Various Solvents

compd	Ar/solvent	CCl_4	$CDCl_3$	CD_3CN	DMSO
b[a]	*p*-BrC_6H_4	96/4	81/19	3/97	0/100
	Ph	97/3	87/13[b]	5/95	0/100
	p-Tol	100/0[c]	87/13	4/96	0/100
	p-An	100/0[d]	88/12	7/93[e]	0/100
	2,4-$(MeO)_2C_6H_3$	100/0	82/18	17/83	0/100
c	*p*-BrC_6H_4	50/20/30	19/10/71	0/0/100	0/0/100
	Ph	51/19/30	19/7/74	0/0/100	0/0/100
	p-Tol	53/23/24[f]	23/12/65	0/0/100	0/0/100
	p-An	55/23/22[g]	24/10/66	0/0/100	0/0/100
	2,4-$(MeO)_2C_6H_3$	60/21/19	21/8/71	0/0/100	0/0/100
d	Ph		67/33/0	19/0/81[i]	0/0/100
	p-Tol	*h*	68/32/0	25/0/75[i]	0/0/100
	p-An	62/38/0	67/33/0		0/0/100
e	*p*-BrC_6H_4	74/15/11	64/12/24	4/0/96[k]	0/0/100
	Ph	77/16/7	64/15/21	3/0/97[k]	0/0/100
	p-Tol	83/17/0[j]	67/13/20	0/0/≥98[k]	0/0/100
	p-An	83/17/0	68/15/17	5/0/95[k]	0/0/100

[a] The ratios given for series **b** are of **8/7** since only one enol was formed. [b] 94/6 in 1:4 $CDCl_3-CCl_4$. [c] 100/0 in 1:9 $CDCl_3-CCl_4$. [d] 81/19 in $Cl_2CDCDCl_2$. [e] 29/71 in THF. [f] 54/22/23 in 1:9 $CDCl_3-CCl_4$; 52/28/20 in 1:4-$CDCl_3-CCl_4$. [g] 63/26/11 in C_6D_6; 89/11 in $Cl_2CDCDCl_2$. [h] 74/26/0 in $Cl_2CDCDCl_2$. [i] The signal for *Z*-**8** was not observed, probably due to broadening which was observed for the H derivative. [j] Value in 1:9 $CDCl_3-CCl_4$. [k] The signal for *Z*-**8** was not observed due to its low intensity.

The ^1H (and ^{19}F) spectra of **8c**, Ar = *p*-An in C_6D_6 resemble the spectra in CCl_4, with enol I being the major isomer, but with a better signals separation than in CCl_4 (Table 8).

For the symmetrical system **7b/8b** in $CDCl_3$ and CCl_4, at low field only the three signals ascribed to the single enol and the amide were observed.

The OH signals of both enols appear as doublets with $J = 1.0-1.6$ Hz. They are coupled to the NH signal which is broad due to N−H coupling but the $^4J_{HH}$ coupling is observed by a COSY spectrum.

Other signals display a proper integration. The aromatic signals are AB quartets for the *para*-substituted systems. Signals for the three (two for **7b/8b**) species are observed in the aromatic region and when integration is not obstructed by overlap, the ratios obtained resemble within the experimental error those obtained by integration of the OH and NH signals. The signals of the esters are mostly complex due to overlap of signals of the various species and coupling to fluorine atoms. For example, the signals of esters **8b** frequently display one quartet due to overlap of the two signals of the CH_2CF_3 groups.

Only the amide signals are observed for all compounds in DMSO-d_6 (i.e., $K_{Enol} \leq 0.02$). The spectrum of **7c**, Ar = *p*-BrC_6H_4 is a representative example (Figure 5). In CD_3CN the **c** family compounds exist as the amides **7c**, and with three exceptions, the enol is <7% in other cases and only *E*-**8** is observed. Two of the exceptions are *E*-**8d** which represents 19−25% of the mixture whereas the signal for *Z*-**8d** is barely observed and **8b**, Ar = 2,4-$(MeO)_2C_6H_3$, which is present in 17%.

^{19}F NMR. ^{19}F NMR is a very useful tool in determining the number of species and their relative ratios. Complications similar to those mentioned above are reduced and each species **7c/8c**, **7e/8e** show one signal in the non-coupled spectrum. The unsymmetrical **7d/8d** show two signals for each species, and the various signals are identified by their integration and splitting in the coupled F−H spectra. Small signals at $\delta = -78.45$ (δ_F of CF_3-CH_2OH) as well as the appearance of small unidentified signals in the ^1H and ^{13}C spectra indicate some decomposition of the amide/enol systems. The decomposition product in one case is given below.

^{13}C NMR. The ^{13}C NMR spectra are consistent with the assignments given above. This is illustrated for **7c**/**8c**, Ar = *p*-BrC_6H_4 in CCl_4 in Figure 6 where the enols predominate, and in Figure 7 in DMSO-d_6 where the amide is the only species. Important features for structural assignment are the two signals of low to medium intensity at δ 74−76 (cf. the spectra of **7c**/*E*-**8c**/*Z*-**8c** in Figure 6) which are ascribed to C_β (the esters-substituted carbon) of the enols **8**. Such a low field position for a vinylic carbon is expected for the push−pull enol, as found previously for C_β of **4**.[6a] From the relative intensities, C_β of Enol I is at a higher field than that of Enol II. The symmetrical systems **7b/8b** display only one $^{13}C_\beta$ signal.

The low field ^{13}C NMR spectra distinguish between the enols and the amide. The amide display one amide carbonyl signal and two C=O ester signals for the nonsymmetrical systems, or only one for **7b**. As discussed above in the solid state ^{13}C spectra all the C=O amide signals are at a field >165.8 ppm. The δ values assigned to the amide species are corroborated by the δ values in DMSO-d_6 where only the amide is present (Figure 7). For both enols the lowest field ^{13}C signals are at a lower field than those of the amide. The signals of Enol I at δ 170−175 are at a lower field than those of Enol II (Figure 6). The number of the low field signals (3 for each enol, either when both enols or only one enol are present) exceeds the number of ester C=O groups, and we conclude that C_α appears in this region. This is again consistent with precedents, e.g., for C_α of **4**[6a] and many other enamines with β-EWGs[17] and with the push−pull nature of the enol, since the OH,NHPh-substituted C_α is highly positive in the zwitterionic hybrid **1b**.

In the ^{13}C hydrogen coupled spectrum the two low field signals of **8b**, X = An, at δ 167.35 and δ 172.37 are triplets, whereas that at δ 170.76 is a doublet. We ascribe the former signals to ester groups, coupled with the CH_2 hydrogens, and the latter signal to C_α which is coupled to the enolic OH. Hence, $\Delta^{13}C(C_\alpha-C_\beta) = 96$ ppm, a value close to that found for related systems.[6] Similar coupling patterns appear for other systems.

The two CH_2CF_3 ester groups in compounds **8b** are different. In the ^{19}F-coupled spectra, e.g., when Ar = *p*-BrC_6H_4 (Figure 8A) two CH_2 quartets of apparently the same intensity are observed. Two sets of signals for the CF_3 carbons which are coupled to the CH_2 hydrogens are also observed (Figure 8B). Likewise, two CH_2 signals of identical intensity are observed in the ^1H spectrum (Figure 8C), and two ^{19}F signals of identical intensity are observed in the ^{19}F spectrum whereas the amide gives only one ^{19}F signal.

A significant characteristic feature is the $C_\alpha-H$ coupling for the amide. The $^1J_{CH}$ values of ca. 132−137 ppm are characteristic for $C_{sp^3}-H$ coupling.

^{17}O NMR. The ^{17}O NMR data in $CDCl_3$, CCl_4, and CD_3CN are given in Table 10 for the eight systems of **7b/8b** and **7c/8c** and for **7e/8e**, Ar = Ph. The spectra in $CDCl_3$ display signals at three regions. Signals at δ 350−356

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Table 9. *E*-8/*Z*-8 Ratios and K_{Enol} Values in Various Solvents[a]

		CCl_4		$CDCl_3$		CD_3CN		DMSO-d_6	
compound	Ar	*E*-**8**/*Z*-**8**	K_{Enol}	*E*-**8**/*Z*-**8**	K_{Enol}	*E*-**8**/*Z*-**8**	K_{Enol}	*E*-**8**/*Z*-**8**	K_{Enol}
E-**8b**/*Z*-**8b**/**7b**	*p*-BrC_6H_4	–	24	–	4.3	–	0.03	–	≤0.02
	Ph	–	32	–	6.7[b]	–	0.05	–	≤0.02
	p-Tol	–	≥50[c]	–	6.7	–	0.04	–	≤0.02
	p-An	–	≥50[d]	–	7.3	–	0.08[e]	–	≤0.02
	2,4-$(MeO)_2C_6H_3$	–	≥50	–	4.6	–	0.20	–	≤0.02
E-**8c**/*Z*-**8c**/**7c**	*p*-BrC_6H_4	2.5	2.3	1.9	0.41	–	≤0.02	–	≤0.02
	Ph	2.7	2.3	2.7	0.35	–	≤0.02	–	≤0.02
	p-Tol	2.3[f]	3.2[g]	1.9	0.54	–	≤0.02	–	≤0.02
	p-An	2.4[h]	3.5[i]	2.4	0.52	–	≤0.02	–	≤0.02
	2,4-$(MeO)_2C_6H_3$	2.9	4.3	2.6	0.41	–	≤0.02	–	≤0.02
E-**8d**/*Z*-**8d**/**7d**	Ph	–	–	2.0	≥50	–	0.23	–	≤0.02
	p-Tol	–[k]	–	2.1	≥50	–	0.33	–	≤0.02
	p-An	1.6	≥50	2.0	≥50	–	–	–	≤0.02
E-**8e**/*Z*-**8e**/**7e**	*p*-BrC_6H_4	4.9	8.1	5.3	3.2	–	≤0.02	–	≤0.02
	Ph	4.8	13.2	4.3	3.8	–	≤0.02	–	≤0.02
	p-Tol	4.9[l]	≥50[l]	5.1	3.3	–	≤0.02	–	≤0.02
	p-An	4.9	≥50	4.5	4.9	–	≤0.02	–	≤0.02

[a] Based on average values. The values ≥50 and ≤0.02 for K_{Enol} mean that no amide or no enol, respectively, were observed, since 2% of each could have been observed. [b] 15.7 in 1:4 $CDCl_3$–CCl_4. [c] >50 in 1:9 $CDCl_3$–CCl_4. [d] 4.3 in $Cl_2CDCDCl_2$. [e] 0.61 in THF. [f] 1.86 in 1:4 $CDCl_3$–CCl_4; 2.5 in 1:9 $CDCl_3$–CCl_4. [g] 3.5 in 1:4 $CDCl_3$–CCl_4; 3.3 in 1:9 $CDCl_3$–CCl_4. [h] 2.4 in C_6D_6. [i] 8.1 in C_6D_6 and in $Cl_2CDCDCl_2$. [j] 2.8 in in $Cl_2CDCDCl_2$. [k] ≥50 in $Cl_2CDCDCl_2$. [l] Value in 1:9 $CDCl_3$–CCl_4.

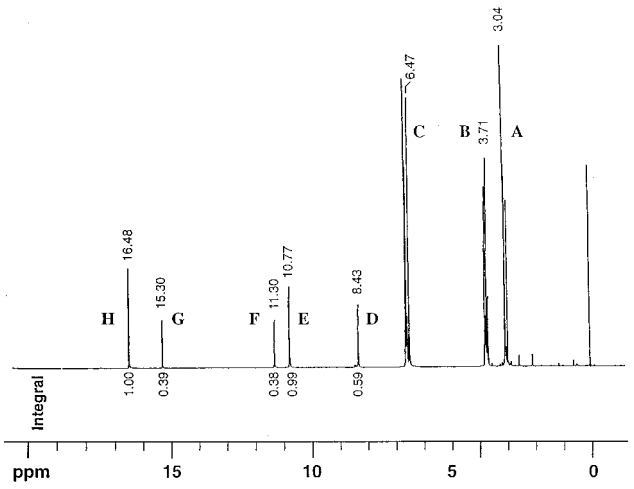

Figure 4. ^1H NMR spectrum of the mixture of **7c**/*E*-**8c**/*Z*-**8c**, Ar = *p*-BrC_6H_4, in CCl_4 at room temperature. A: Me region; B: CH_2 + CH region; C: Aromatic region; D: NH of **7c**; E: NH of *E*-**8c**; F: NH of *Z*-**8c**; G: OH of *Z*-**8c**; H: OH of *E*-**8c**.

and at 133–144 ppm are assigned to the ester carbonyl and methoxy groups, respectively, in line with those found for the enols of esters in the polycarbomethoxycyclopentadiene systems.[18] The third region is at 210–290 ppm which we ascribe to the oxygen of the enolic moiety due to three reasons. First, the enolic ^{17}O signals in the enols of polycarbomethoxycyclopentadienes are at 221–225 ppm,[18] and the oxygens of the fluorinated enols are expected to be approximately in this region. Second, the spectra in CCl_4 where the enol is the major species according to the other spectra contain fewer signals, one each in these three regions, and only for **7c**/**8c**, Ar = *p*-An and Ar = *p*-Tol, one signal and four signals, were respectively observed. In the latter case one signal is at 233 ppm. Third, the signal in the 210–290 ppm region is completely absent in MeCN, where the enols are not present at all or only in minor amounts.

Most of the amides display only two signals in MeCN. The carbonyl signals are at the narrow range of 362–373 ppm for series **8b** and **8c** and at 352 ppm for **8e**, Ar = Ph, and the methoxy signals appear at 138–147 ppm. The carbonyl groups of amides usually appear at the 267–367 ppm range, mostly at 300–330 ppm.[19] Two carbonyls of the ester and the amide groups are expected for series **8b** and three for series **8c** and for **8e**, Ar = Ph, where the ester groups differ. That only one signal is observed is ascribed to the large widths of the signals (Table 10), and it suggests that all the carbonyls appear in a relatively narrow range. We ascribe the signals appearing at 34–50 ppm to decomposition products including trifluoroethanol.

Most of the carbonyl signals are at lower δ values in CCl_4 and $CDCl_3$ than in MeCN, indicating that the C=O signals of the enols are at a higher field than those in the amide. However, since (a) the composition changes with the solvent, (b) the aryl substituent affects the shifts, (c) the signals are wide, and (d) as much as nine C=O signals are expected in the chlorinated solvents, but at most only four are observed, there are only two warranted qualitative conclusions: (i) Enols of amides are present, and their $\delta(^{17}O)$ are in the 210–290 ppm range and (ii) the enols vs amides ratios in the various solvents corroborate the deduction from the ^1H and ^{19}F spectra.

^{15}N NMR. The ^{15}N NMR spectra (Table 10) that are the simplest spectra, since each species contains only one nitrogen, lead to similar conclusions. Only one signal is observed at δ = −246.8 to −249.9 (reference $Me^{15}NO_2$) ppm in MeCN and is ascribed to the amido nitrogen. Amido nitrogens usually appear at −245 to −280 ppm.[20] In contrast, all compounds except **8e**, R = Ph, display in CCl_4 signals at the −260.1 to −263.3 ppm range.

Two compounds, **8c**, Ar = Ph and *p*-BrC_6H_4, display two signals at ca. −253, and at −261.6 and −263.1 ppm, respectively, which we ascribe to the amide and the enols,

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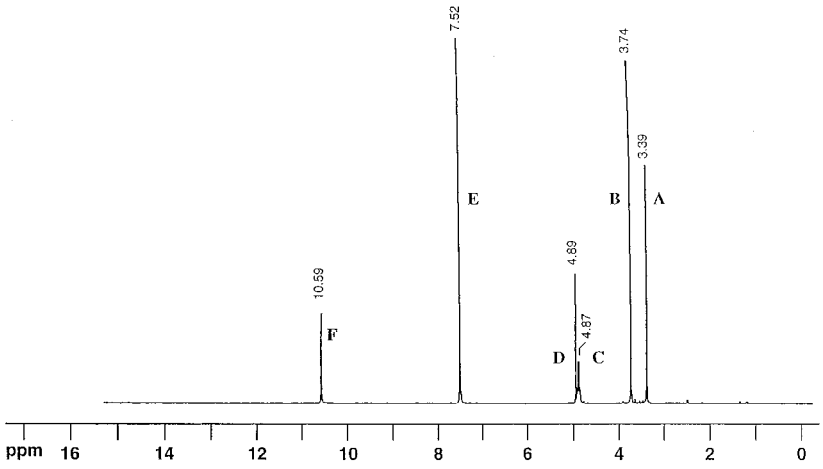


Figure 5. ^{1}H NMR spectrum of **7c**, Ar = *p*-BrC_6H_4, in DMSO-d_6 at room temperature. A: Solvent; B: Me; C: CH_2; D: CH; E: Ar; F: NH.

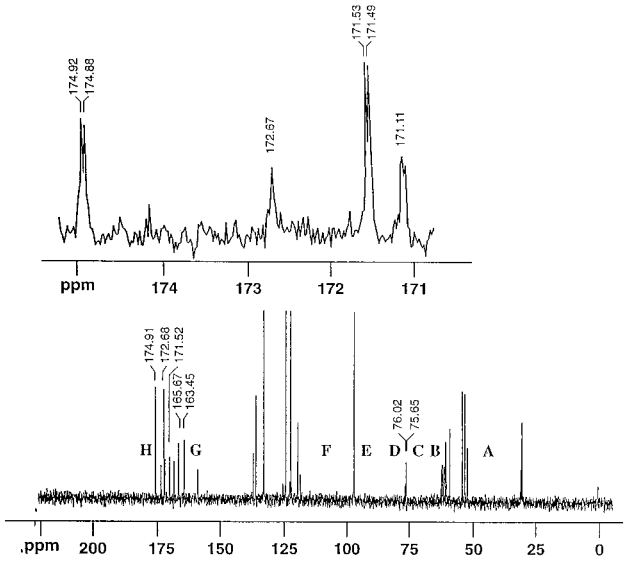


Figure 6. ^{13}C NMR spectrum of the **7c**/*E*-**8c**/*Z*-**8c**, Ar = *p*-BrC_6H_4, mixture in CCl_4 at room temperature. A: Me region; B: CH_2 region; C: C_β of *E*-**8c**; D: C_β of *Z*-**8c**; E: Solvent; F: Ar region; G: CO region of **7c**; H: CO region and C_α of *E*-**8c** and *Z*-**8c**. Inset: Splitting of the low field signals in the proton-coupled spectrum.

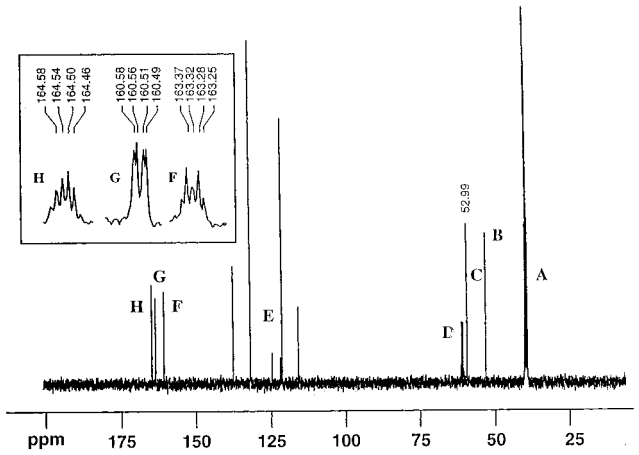


Figure 7. ^{13}C NMR spectrum of **7c**, Ar = *p*-BrC_6H_4, in DMSO-d_6 at room temperature. A: solvent; B: Me; C: CH; D: CH_2; E: Ar; F: CoH; G, H: COO region. Inset: splitting of the low field signals in the proton-coupled spectrum.

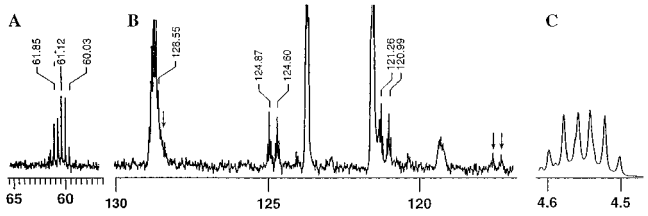


Figure 8. Spectral evidence for the presence of two different $CO_2CH_2CF_3$ groups in enols **8b**. A: Two overlapping CH_2 quartets in the ^{19}F coupled ^{13}C spectrum of **8b**, Ar = *p*-BrC_6H_4. B: Two pairs of quartets of triplets for the CF_3 signals in the ^{13}C spectrum coupled to the CH_2 hydrogens of **8b**, Ar = *p*-BrC_6H_4. C: Two overlapping CH_2 quartets in the F-coupled ^{1}H spectrum of **8b**, Ar = *p*-Tol.

respectively. The situation is more complex in $CDCl_3$. Each compound for system **7c/8c** display a signal at −253.5 to −256.5 ppm and two of them also at the −264.2 to −265.9 ppm range. The latter values are ascribed to the enols and the former to the amide, and indeed in the **7b/8b** series for most compounds δ = −262.6 to −264.3 and only the *p*-anisyl derivative displays two additional signals at −256.2 and −256.7.

These results lead to the following conclusions. (a) The $\delta(^{15}N)$ range in CCl_4 is consistent with the expectation for the nitrogen of the enol. Whereas simple enamines resonate at −301 to −352 ppm vs $Me^{15}NO_2$ reference,[21] β-EWGs induce a significant shift and for 2-acylenamines $\delta(^{15}N)$ = −247 to −314 ppm, close to that for amides. A closer model is the phenylenamino diester $(EtO_2C)_2C{=}$CHNHPh for which $\delta(^{15}N)$ = −251.8 ppm in both $CDCl_3$ and DMSO-d_6 (with $^1J_{NH}$ = 91.9 and 92.7 Hz, respectively). Although a solvent effect on the shift in other solvents was not found for this compound or for $(MeCO)_2$-C=CHNHPh [$\delta(^{15}N)$ = −247.6 ($CDCl_3$) and −247.5 (DMSO-d_6)], a solvent effect may exist in our system since increased solvent polarity sometimes causes substantial downfield shifts. For example, for (*E*)-3-dimethylamino-acrolein $\delta(^{15}N)$ = −289.0 ($CDCl_3$), −294.1 (C_6D_6), −305 (CD_3OD). (b) The two enols probably have similar ^{15}N shifts, since mostly only one signal was observed and

Table 10. ^{17}O and ^{15}N NMR Data for ArNHCOCH(CO_2R)CO_2R'/ArNHC(OH)=C(CO_2R)CO_2R' (7/8)

A. ^{17}O NMR[a]

Ar	R	R'	$CDCl_3$, ppm	CCl_4, ppm	MeCN, ppm
C_6H_5	Me	$CH(CF_3)_2$	350, 334, ca 298, 259, 141	355, 138, 113	352, 138
C_6H_5	CH_2CF_3	CH_2CF_3	358, 303, 261, 139	315, 269, 136	373, 147
4-$MeOC_6H_4$	CH_2CF_3	CH_2CF_3	360, 290, 235[b], 134[b]	344[b], 284, 135	370, (343), 139, (40)
4-MeC_6H_4	CH_2CF_3	CH_2CF_3	304, 246, 210, 129	300, 236, 135	369, 144
4-BrC_6H_4	CH_2CF_3	CH_2CF_3	345, 284, 220, 133	290, 220, ca.138	365, 140
C_6H_5	Me	CH_2CF_3	353, 290, 144	348, 280, 138	362, 141
4-$MeOC_6H_4$	Me	CH_2CF_3	355, 279, 140, 34[b]	ca. 130	365, 143, ca.50
4-MeC_6H_4	Me	CH_2CF_3	356, 144	365, 297, 233, 145	363, 138
4-BrC_6H_4	Me	CH_2CF_3	354, 260[b], 141	345, 284, 143	364, 144

B. ^{15}N NMR[c]

Ar	R	R'	$CDCl_3$, ppm (^1J(N−H))	CCl_4, ppm (^1J(N−H))	MeCN, ppm (^1J(N−H))
C_6H_5	Me	$CH(CF_3)_2$	−253.1 (89.1)	−251.9 (90.3)	−249.4 (94.0)
C_6H_5	CH_2CF_3	CH_2CF_3	−262.6 (91.5)	−260.1 (97.7)	−246.8 (90.3)
4-$MeOC_6H_4$	CH_2CF_3	CH_2CF_3	−256.2, −256.7 (90.9, 90.9), −264.2 (90.3)	−261.6 (90.3)	−248.9 (89.3)
4-MeC_6H_4	CH_2CF_3	CH_2CF_3	−263.0 (91.6)	−260.5 (89.1)	−247.5 (91.5)
4-BrC_6H_4	CH_2CF_3	CH_2CF_3	−264.3 (90.3)	−261.8 (90.3)	−247.8 (89.1)
C_6H_5	Me	CH_2CF_3	−253.5, −254.2 (90.3, 90.3), −264.2 (87.9)	−251.3, −261.6 (90.3, 90.3)	−247.0 (91.5)
4-$MeOC_6H_4$	Me	CH_2CF_3	−256.5, −265.9 (91.6, 92.8)	−263.3 (87.9)	−249.1 (90.3)
4-MeC_6H_4	Me	CH_2CF_3	−255.2 (91.5)	−262.0 (92.8)	−249.9 (91.5)
4-BrC_6H_4	Me	CH_2CF_3	−255.8 (90.3)	253.6, −263 (91.6, 86.7)	−248.1 (91.5)

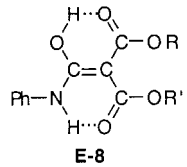
[a] ^{17}O half-line widths are 360−1200 Hz. Many of them are not reliable due to overlap with a neighboring signal or to the low intensity. [b] The presence of the signal is not clear due to the poor quality of the spectrum. [c] δ values vs $Me^{15}NO_2$ reference.

when two signals were observed they are close to one another. (c) The sensitivity of the method is low, since mostly it does not detect the small amount of amide in CCl_4.

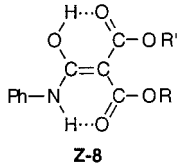
We conclude that in the absence of a close model, the ^{15}N shifts can be used only for corroboration of results from other spectra, i.e., that the species formed is different in CD_3CN and CCl_4, but an a priori use of these values for structural assignment is unwarranted.

Finally, the $^1J_{NH}$ coupling constants for all compounds in all the solvents are very similar, being 87.9−94.0 ppm. These values resemble those found for other enamines with EWGs as well as those of amides, and hence they are not diagnostic.[17,20]

Structures of the Two Enols in Solution. The similarity of the CP-MAS ^{13}C NMR solid spectra of the six- and nine fluorine-substituted systems to those of the major species in $CDCl_3$ and CCl_4 solution, and the similarity of the spectra of the various species in solution clearly indicate that Enol I is an enol of an amide, rather than an enol of an ester. This is consistent with the earlier finding for enols **4** and **6** and for enols **1**, R^1 = CO_2R, R^2 = NO_2, CN or R^1 = R^2 = CN.[6] What is the structure of Enol II? An enol of ester had never been observed so far for systems carrying a $C(CO_2R)CONR^{III}R^{IV}$ moiety, but both cis (*E*) and trans (*Z*) enols of amides (*E*-**8** and *Z*-**8**) or of esters (*E*-**10** and *Z*-**10**), as well as are two additional enols of the latter esters where R and R′ exchange positions, could be observed provided that they do not interconvert rapidly on the NMR time scale. On the basis of the observations summarized above the observed enols are *E*-**8** and *Z*-**8**.



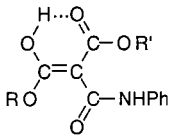
E-8



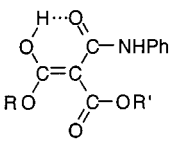
Z-8

R is less fluorinated group

A strong argument for these structures is the regular behavior of series **7/8** when the number of the fluorine atoms increases as described below. Moreover, two enols were observed in systems **8c**, **8e**, and **8d** containing three, six, and nine fluorine atoms in two different ester groups, but only a single enol is observed in systems **8b** containing six fluorine atoms in two identical ester groups. There should be no isomers of **8** although the groups are magnetically nonequivalent as is indeed observed. In contrast, *E*-**10** and *Z*-**10** differ even if the ester groups are identical. Arguments concerning a rapid $E \rightleftharpoons Z$ isomerization are discarded since they equally apply for the systems where the two isomers were observed.



E-10



Z-10

From the solid-state structures the less fluorinated ester group is a better hydrogen bond acceptor and hence it should preferentially form an hydrogen bond to a *cis*-OH group over the more fluorinated ester group. The analysis in solution requires that formation of both *E*-**8** and *Z*-**8** should be considered. On the basis of the solid-state O···O, O···N, O···H−O and O···H−N distances and the expected correlation between them and the strength of hydrogen bonds,[21] the C(=O)···H−O hydrogen bond should be stronger than the C(=O)···H−N bond. Consequently, *E*-**8** with the better hydrogen bond CO_2R acceptor should be more stable than *Z*-**8** with a weaker hydrogen bond to the OH, although the hydrogen bond to the NH is stronger in *Z*-**8**.

This situation leads to several predictions assuming that "Enol I" is *E*-**8** and "Enol II" is *Z*-**8**. First, the δ(OH) of *E*-**8** should be at a lower field than that for *Z*-**8**. Second,

(21) Reference 17, pp 294−299 and 325−390.

Table 11. Chemical Shift Differences (in ppm) between Enol I and Enol II of *p*-$XC_6H_4NHC(OH)=C(CO_2R)CO_2R'$ in $CDCl_3$

X	R	R'	δ(OH)[a]	δ(NH)[a]	$\Delta\delta$(OH)[b]	$\Delta\delta$(NH)[b]	$\Delta\delta$(OH, NH)[c,d]	% Enol II[e]
Br	Me	$CH(CF_3)_2$	17.25	11.24	2.00	−0.84	6.02, 3.20	17
H			17.06	11.22	1.92	−0.78	5.84, 3.24	17
Me			17.01	11.14	2.04	−0.76	5.96, 3.16	19
MeO			16.86	11.07	1.85	−0.76	5.79, 3.18	19
Br	Me	CH_2CF_3	17.22	11.50	1.13	−0.48	5.72, 4.11	29
H			17.06	11.48	1.08	−0.45	5.57, 4.04	25
Me			16.94	11.39	1.06	−0.45	5.54, 4.03	29
MeO			16.87	11.31	1.09	−0.45	5.50, 3.90	29
2,4-$(MeO)_2$			16.93	11.50	1.04	−0.37	5.43, 4.02	27
H	CH_2CF_3	$CH(CF_3)_2$	16.04	11.37	0.82	−0.34	4.67, 3.51	33
Me			15.93	11.29	0.80	−0.34	4.64, 3.50	33
MeO			15.86	11.22	0.79	−0.33	4.64, 3.52	29

[a] Values for Enol I. [b] Difference between Enol I and Enol II. [c] Differences for each enol. [d] For R = R′ = CH_2CF_3 δ(OH), $\Delta\delta$(OH, NH): 16.15, 4.51 (Br), 16.13, 4.44 (H), 15.92, 4.39 (Me), 15.85, 4.44 (MeO); 15.93, 4.28 (2,4-$(MeO)_2$). [e] In the enol mixture.

since in all our systems the group bonded to the OH is either CO_2Me or $CO_2CH_2CF_3$ we expect to observe two discrete regions of δ(OH) with that for the *cis*-CO_2Me group being at a lower field, with a small influence of the other ester group. Third, since the hydrogen bond to the NH will be stronger for cis N−H and CO_2Me groups, the δ(NH) should shift simultaneously to a lower field when the OH is shifted to an upper field. Hence, the OH and the NH signals of *Z*-**8** should become closer to one another when those of *E*-**8** become further apart. The $\Delta\delta$-(OH) between the two isomers should increase and $|\Delta\delta$-(NH)| should also increase, but will have a negative sign, when the two ester groups become more different. Fourth, the *E*-**8**/*Z*-**8** ratio should increase when the difference in the number of fluorine atoms in the two ester groups will increase. The highest percentage of *E*-**8** is expected for enols **8e** and the lower percentage for **8c** and **8d**.

The data in Table 11 show that these predictions are fulfilled. In $CDCl_3$ the average δ(OH) values for the different aromatic substituents are 17.05 and 17.00 for enols *E*-**8c** and *E*-**8e** having *cis*-CO_2Me/OH groups. Remarkably, the previously reported δ(OH) value of **6** is 17.05.[6a] For enols *E*-**8d** and the single isomer of **8b**, with *cis*-$CO_2CH_2CF_3$/OH groups, the δ(OH) values are again similar, but lower, being 15.94 and 16.00 ppm.

The average $\Delta\delta$(OH) (= δ(*E*-**8**) − δ(*Z*-**8**)) value decreases from 1.95 for the pair R = Me, R′ = $CH(CF_3)_2$ to 1.08 for R = Me, R′ = CH_2CF_3, to 0.80 for R = CH_2CF_3, R′ = $CH(CF_3)_2$. The value when R = R′ = CH_2CF_3 is 0, so that the change is regular.

The average δ(NH) value of *E*-**8** decreases from 17.06 for R = Me, R′ = $CH(CF_3)_2$ to 15.95 for R = CH_2CF_3, R′ = $CH(CF_3)_2$. The average $\Delta\delta$(NH) = δ(*E*-**8**) − δ(*Z*-**8**) values are −0.78, −0.47, and −0.34 ppm for the R,R′ pairs Me, $CH(CF_3)_2$; Me, CH_2CF_3, and CH_2CF_3, $CH(CF_3)_2$, respectively.

The percentage of *Z*-**8** increases from 18% via 28% to 32% for the same three pairs. The plots of the % of *Z*-**8** vs $\Delta\delta$(OH) (Figure 9) or vs $\Delta\delta$(NH) (not shown) are linear.

Consequently, the deduction that enol I/enol II are the *E*-**8**/*Z*-**8** isomers is quantitatively corroborated based on the assumption that the relative strengths of the C=O···HO and C=O···HN hydrogen bonds determine the *E*-**8**/*Z*-**8** ratios.

Solvent Effect on the Enols/Amide Ratios. The enols/amide ratios (given as *E*-**8**/*Z*-**8**/**7** ratios in Table 8) depend strongly on the solvent polarity. Ratios in the low dielectric chlorinated solvents CCl_4, $CDCl_3$, $Cl_2CDCDCl_2$, CCl_4−$CDCl_3$ mixtures, and C_6D_6 differ from those in the high dielectric aprotic solvents CD_3CN and DMSO-d_6.

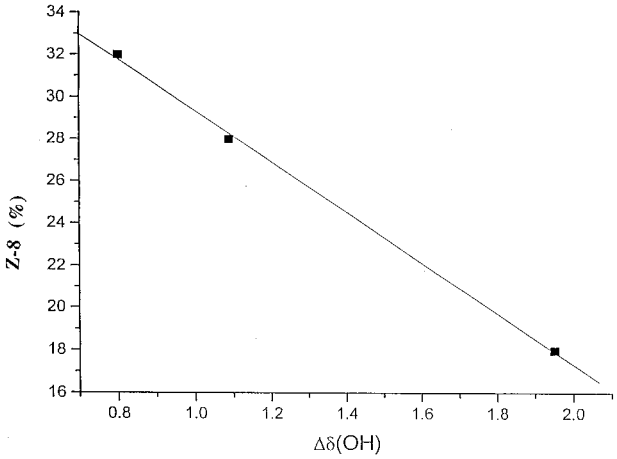


Figure 9. A plot of the average percentage of enols *Z*-**8** for systems **8c**−**e** vs the average $\Delta\delta$(OH) values in these systems.

The product distribution show the following characteristics: (a) The percentage of the enols is the highest in CCl_4 and decreases on increasing the polarity of the solvent. For example, in CCl_4 the enols are 70−81% for **8c**, 89−100% for **8e**, 100% for **8d** (Ar = *p*-An), and 96−100% for **8b**. In $CDCl_3$ the enols are >75% (except for 26−35% for **8c**) being 100% for **8d**. In CD_3CN the enols are ≤7% for **8b**, **8c**, and **8e** except for **8b**, Ar = 2,4-$(MeO)_2C_6H_3$, and 19 and 25% for **8d**, Ar = Ph, *p*-Tol. In DMSO-d_6 only the amides are observed, and the spectra of **7** required for the analysis are obtained in DMSO-d_6. Figure 5 shows the absence of $\delta(^1HO)$ signals in DMSO-d_6; the characteristic higher field amide signals compared with those of the enol(s) in the low field ^{13}C NMR spectra are shown in Figure 6, and the absence of the enol's $^{13}C_\beta$ signal and the appearance of a C−H signal in the hydrogen coupled ^{13}C NMR spectrum are shown in Figure 7. The ^{17}O NMR spectra in MeCN (Table 10) show only signals characteristic of carbonyl and methoxy ester oxygens.

(b) The percentage of the enol(s) increases on increasing the number of CF_3 groups in the esters. In $CDCl_3$ the lowest percentage is for the nonfluorinated **6**,[6a] followed by the trifluoro-substituted **8c**. Only enols were observed for the nonafluoro-substituted enols **8d**, Ar = Ph, *p*-Tol. In CD_3CN the enols were not observed for system **8c** but 17−25% enols were observed for **8b** (Ar = 2,4-$(MeO)_2C_6H_3$) and **8d** (Ar = Ph, *p*-Tol).

(c) Although the percentage of enols sometimes increases on increasing the electron-donating ability of the ring substituent, the effect is small and mostly nonsystematic.

(d) The *E*-**8**/*Z*-**8** ratios (Table 9) were measured only for a few systems since *Z*-**8** was not formed at all in CD_3CN and DMSO-d_6 and due to the low solubility of **8d** in CCl_4. The ratios are slightly higher for **8c** in CCl_4 than in $CDCl_3$ and are nearly identical for **8e** in the two solvents and higher in $CDCl_3$ for **8d**, Ar = *p*-An. Consequently, no trend was found, although the ratios are significantly higher for systems **8e** than for **8c** and **8d**.

The decrease of the enols/amide ratios on increasing the solvent polarity contrasts the significant increase of K_{Enol} for aryl-substituted enols on increasing the solvent polarity.[22] However, K_{Enol} decreases on increasing the polarity for 1,3-diketones such as acetylacetone which are closer analogues of our enols and likewise are strongly intramolecularly hydrogen bonded.[9] We ascribe this behavior to a preferential solvation of the more polar amide in the more polar solvent.[23] In the zwitterionic hybrid of the hydrogen bonded enol the partial positive charges on the C_α(OH)NHPh moiety are "intramolecularly solvated" by the partial negative charges on the ester carbonyls. Apparently, replacing this hydrogen bond by an intermolecular hydrogen bond to the solvent is less efficient than the increased solvation of the amide tautomer.

It is interesting that δ(OH) in CCl_4 is consistently ca. 1 ppm to a higher field than in $CDCl_3$. This behavior is inconsistent with a dependence either on the polarity or the hydrogen bond accepting ability of the solvent. The δ(OH) in the analogous 1,3-diketones are $\delta(CCl_4) > \delta(CDCl_3)$ for $(CF_3CO)_2CH_2$, $\delta(CCl_4) \approx \delta(CDCl_3)$ for $(MeCO)_2CH_2$ and $MeCOCH_2COR$ (R= Me, 2-thienyl) and $\delta(CCl_4) > \delta(CDCl_3)$ for $(PhCO)_2CH_2$.[23] We do not have an explanation for the order of the δ(OH) values.

Internal Rotation Around the C=C Bond in the Enols. Internal rotation barriers around the formal C=C bond in push−pull alkenes are much lower than those found for simple alkenes. e.g., ≤25 kcal/mol barriers were observed by dynamic NMR studies for such rotation, e.g., in enamines carrying β-EWGs.[24] Since our enols carry strongly resonatively electron-donating groups on C_α and strongly EWGs on C_β, a rapid *E*/*Z* isomerization by rotation around the C=C bond may take place. However, the rotation is relatively slow on the ^{1}H, ^{19}F, and ^{13}C NMR time scales since separate CH_2CF_3 groups appear in all the spectra of **8b** (cf. Figure 8), whereas only one signal should be observed if fast rotation takes place. Likewise, we did not find any NMR evidence (broadening, coalescence) for *E*/*Z* isomerization in any other system at room temperature.

However, from the EXSY spectrum of **8b**, Ar = *p*-An, at room-temperature k_{isom} = ca. 0.11 s^{-1} ($\Delta G^{\ddagger}$ = 18.7 kcal/mol) for the *E* ⇌ *Z* isomerization, whereas for the enol ⇌ amide interconversion the rate constant is ca. 10^{-3} s^{-1}($\Delta G^{\ddagger}$ = 21.5 kcal/mol).

Decomposition. In a search for the internal rotation, a sample of **8b**, R = *p*-An, was heated to 360 K in $Cl_2CDCDCl_2$, but only small temperature-dependent shifts of the signals were observed. However, when the sample was left for several hours at 360 K, two new signals at the δ(OH) and δ(NH) region had appeared in an irreversible process. The changes were ascribed to decomposition of the enol. Heating of **8b**, R = Ph, for 24 h at 373 K gave 61% of a product identified by NMR spectra and microanalysis as $PhNHCOCH_2CO_2CH_2CF_3$, formed by a loss of an ester group.

Temperature Effect. The enol/amide ratio decreases significantly on increasing the temperature in $Cl_2CDCDCl_2$ for compounds **8b**, Ar = Ph, *p*-Tol, and *p*-An. In the temperature range 260−360 K, plots of ln K_{Enol} vs $1/T$ were linear giving ΔH values of 0.5−1.4 kcal/mol.

Conclusions. Substitution of a dialkyl anilidomalonate $ArNHCOCH(CO_2R)CO_2R'$ by three, six, and nine fluorine atoms in the ester groups increases the relative percentage of the enol(s) in the amide/enol(s) of amide mixture in a rough proportionality to the number of the fluorine atoms. The enol which is <10% when R = R′ = Me in CCl_4,[6a] becomes almost the exclusive component of the mixture when R = CH_2CF_3, R′ = CH_2CF_3, or $CH(CF_3)_2$. In the solid state, the structure is that of the amide for R = Me, R′ = Me, CH_2CF_3 but is that of the enol for compounds with six or nine fluorine atoms. These enols show bond lengths expected for push−pull enamines. ^{1}H, ^{13}C, ^{19}F, ^{15}N, and ^{17}O NMR spectra were used as structural probes for the formation of the enol(s) in solution. Both *E*- and *Z*-enols are formed in solution when R ≠ R′, and the ≥1.6-fold preference of the *E*-enol is ascribed mainly to preferred hydrogen bonding of the OH with the less fluorinated ester group. This bonding is reflected in the δ(OH) values. The percentage of the enols decrease on increasing the solvent polarity in the order $CCl_4 > CDCl_3 > CD_3CN >$ DMSO-d_6, and in DMSO-d_6 only the amide is observed. The effect of the N-substituents on the enols/amide or the *E*/*Z* enol ratios is small. Rotation around the C=C bond of the enol when R = R′ = CH_2CF_3 is hindered on the NMR time scale. The present work increases significantly the number of nonheteroaromatic enols of amides known, points to a regular effect of substituents on their stability, and shows that they should not be regarded as esoteric species.

Experimental Section

General Methods. Melting points, ^{1}H and ^{13}C NMR spectra were recorded as described previously.[25]

Analytical and Spectral Data. Mps and microanalysis data are given in Table 12.

The ^{1}H, ^{19}F, and ^{13}C NMR spectra of all compounds in all solvents studied are given in Tables S34−S36 in the Supporting Information.

Crystallographic Analysis. Data were measured on a ENRAF−NONIUS CAD-4 computer-controlled diffractometer. Cu Kα (λ = 1.54178 Å) radiaton with a graphite crystal monochromator in the incident beam was used. The standard CAD-4 centering, indexing, and data collecting programs were used. The unit cell dimensions were obtained by a least-squares fit of 24 centered reflections in the range of $20 \le \theta \le 28°$. The details of the analysis for each compound are given in Tables S1, S6, S11, S16, S21, and S26, and the crystallographic information are given in Table S37 in the Supporting Information. The *R* values are 0.057−0.089. Many of the fluorine atoms display large thermal parameters in comparison to their nearest neighbor. Several attempts were made at modeling the structures with disordered CF_3 groups, but none of them were successful. The same applies for modeling the

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(23) Floris, B. In *The Chemistry of Enols*; Rappoport, Z., Ed.; Wiley: Chichester, 1990; Chapter 4.
(24) E.g., Sandstrom, J. In *The Chemistry of Enamines*; Rappoport, Z., Ed.; Wiley: Chichester, 1994; Chapter 6, pp 406−434.
(25) Frey, J.; Rappoport, Z. *J. Org. Chem*. **1997**, *62*, 8372.

Table 12. Analytical Data for the Difluoro Ester Amides/Enols 7/8

				calcd %			found, %		
compd	X in *p*-XC_6H_4	formula	mp, °C	C	H	N	C	H	N
7b	MeO	$C_{15}H_{13}F_6NO_6$	116−7	43.18	3.14	3.36	43.37	3.35	3.21
7b	Me	$C_{15}H_{13}F_6NO_5$	90−2	44.90	3.26	3.49	44.97	3.50	3.46
7b	H	$C_{14}H_{11}F_6NO_5$	111−3	43.42	2.86	3.62	43.07	3.01	3.60
7b	Br	$C_{14}H_{10}BrF_6NO_5$	98-9	36.07	2.16	3.00	36.05	2.33	2.76
7b	2,4-$(MeO)_2$[a]	$C_{16}H_{15}F_6NO_7$	112-3	42.96	3.38	3.13	43.22	3.55	3.09
7c	MeO	$C_{14}H_{14}F_3NO_6$	100-1	48.01	4.32	4.00	48.10	4.07	3.97
7c	Me	$C_{14}H_{14}F_3NO_5$	98-9	50.46	4.23	4.20	50.10	4.41	4.14
7c	H	$C_{13}H_{12}F_3NO_5$	60-2	48.91	3.79	4.39	48.97	3.92	4.38
7c	Br	$C_{13}H_{11}BrF_3NO_5$	108-9	39.22	2.78	3.52	39.30	2.92	3.23
7c	2,4-$(MeO)_2$[a]	$C_{15}H_{16}F_3NO_7$	84-5	47.50	4.25	3.69	47.72	4.29	3.55
7d	MeO	$C_{16}H_{12}F_9NO_6$	85-6	39.60	2.49	2.89	39.90	2.66	2.73
7d	Me	$C_{16}H_{12}F_9NO_5$	72-4	40.95	2.58	2.98	40.85	2.62	2.99
7d	H	$C_{15}H_{10}F_9NO_5$	83-5	39.58	2.21	3.08	40.11	2.37	3.07
7e	MeO	$C_{15}H_{13}F_6NO_6$	110-11	43.18	3.14	3.36	43.21	3.26	3.22
7e	Me	$C_{15}H_{13}F_6NO_5$	86−7	44.90	3.26	3.49	44.62	3.53	3.52
7e	H	$C_{14}H_{11}F_6NO_5$	90−2	43.42	2.86	3.62	43.41	3.00	3.37
7e	Br	$C_{14}H_{10}BrF_6NO_5$	98−9	36.07	2.16	3.00	38.40	2.67	3.35

[a] X_2 in $C_6H_3X_2$.

phenyl ring C9−C14 of **8b**, Ar = *p*-Tol. Hydrogen atoms attached to N and O atoms were found in the difference Fourier maps toward the last cycles of refinement. They were not refined. All other hydrogen atoms were placed geometrically and were not refined.

^{17}O, ^{15}N, and ^{19}F NMR Spectra. The NMR spectra were recorded on a Varian VXR-300 spectrometer, equipped with a Sun 3/60 computer and with a 10 mm broadband probe. The ^{17}O spectra were determined at 40.662 MHz in the FT mode at a probe temperature of 298 K and at natural isotopic abundance. Concentrations were in the order of 90−160 mg per 3 mL of CCl_4, $CDCl_3$, and MeCN, varying as a function of the maximum solubility. Number of scans varied largely, depending on the broadness of the signals and was in the 300000−4000000 range. The signals were referenced to external deionized water by the substitution method. The instrumental settings were similar to those previously reported.[18] The reproducibility of the chemical shift data is estimated to be ±1 ppm, or ±2 ppm for signals either overlapping or broader than 600 Hz.

^{15}N spectra were obtained similarly except for the samples in CCl_4, where a coaxial 3 mm o.d. tube, containing D_2O, was inserted in the 10 mm o.d. NMR tube for lock purpose. The nominal frequency was 30.396 MHz, and the INEPT pulse sequence was used. Spectra were obtained as ^{1}H coupled and not refocused, at a probe temperature of 298 K. The *J* value used was 90 Hz, relaxation delay 2.0 s, and acquisition time 0.5 s. Number of scans varied in the range 160−32000. The reference used was 90% $HCONH_2$ in DMSO-d_6 for which δ = 268.0 ppm compared with the literature standard reference of $Me^{15}NO_2$. The shifts were converted to those against $Me^{15}NO_2$. The reproducibility of the chemical shift data is estimated ±0.1 ppm and that of the *J*'s within ±0.5 Hz.

^{19}F NMR spectra were recorded on Bruker DRX 400 MHz pulsed FT spectrometer operating at 376.50 MHz, spectra width 100.000 Hz, acquisition delay 2 s, pulse angle 90° (pulse width 17.81 ms). Number of scans is 8 for ^{1}H-decoupled and 16 for ^{1}H-coupled fluorine NMR, respectively. $CFCl_3$ is used as a reference (δ ($CFCl_3$) = 0).

CP-MAS ^{13}C NMR Spectra. These were recorded at room temperature using a Varian UNITY INOVA spectrometer with a 9.39 T wide bore magnet operating at 100.576 MHz. The measurements were performed with a probe having a 7 mm zirconia rotor, at spinning rates of 4 and 6 kHz. Typical parameters were as follows: 500 transients; spectral width: 50000 Hz; 1024 data points; contact time, 8 ms; recycle delay 4s.

1,1,1,3,3,3-Hexafluoroisopropyl Methyl Malonate (9e). To a stirred solution of 1,1,1,3,3,3-hexafluoro-2-propanol (15 g, 89 mmol) and *N*,*N*-dimethylaniline (10 g, 82 mmol) in dry methylene chloride (30 mL) in a $CaCl_2$ moisture-protected flask was added a solution of methyl 3-chloro-3-oxopropanoate (9 g, 66 mmol) in dry methylene chloride (15 mL) slowly and dropwise. After the addition was complete, the mixture was refluxing from the heat evolved. The mixture was then refluxed for 3 h and then allowed to stand overnight at room temperature. Methylene chloride (20 mL) was added, followed by water (30 mL), the layers were separated, the aqueous phase was extracted with methylene chloride, and the combined organic phase was washed with 10% aqueous H_2SO_4, followed by a saturated aqueous $NaHCO_3$ solution, and dried (Na_2SO_4). The solvent was evaporated under reduced pressure, and the residue was distilled in vacuo to give 11.6 g (65%) of the diester as a colorless liquid. Anal. Calcd for $C_7H_6F_6O_4$: C, 31.36; H, 2.26. Found: C, 30.92; H, 2.28%.

^{1}H NMR ($CDCl_3$, 240 K) δ: 3.61 (2H, s), 3.70 (3H, s), 5.81 (1H, heptet, J = 6 Hz). No lower field signal was observed. ^{1}H NMR ($CDCl_3$, 298 K) δ: 3.56 (2H, s), 3.74 (3H, s), 5.77 (1H, heptet, J = 6 Hz). ^{19}F NMR ($CDCl_3$, 240 K) δ: −74.41 (d, J = 5.6 Hz); ^{13}C NMR ($CDCl_3$, 298 K) δ: 40.12 (t, J = 132 Hz), 52.74 (q, J = 148 Hz), 67.08 (d of heptets, $J_{doublet}$ = 151 Hz, J_{heptet} = 35 Hz), 120.21 (q of m, $J_{quartet}$ = 282 Hz), 163.46 (m), 165.10 (m).

Reaction of 1,1,1,3,3,3-Hexafluoroisopropyl Methyl Malonate with Aryl Isocyanates. The following procedure is representative also for the reactions of the *p*-Br, *p*-Me, and *p*-OMe phenyl isocyanates.

To a solution of 1,1,1,3,3,3-hexafluoroisopropyl methyl malonate (0.67 g, 2.5 mmol) in THF (5 mL) were added triethylamine (0.51 g, 5 mmol), and phenyl isocyanate (0.3 g, 2.5 mmol), and the mixture was stirred for 24 h. It was then poured into ice-cooled 2 N HCl solution (50 mL) with stirring and extracted with EtOAc, the phases were separated, the organic phase was dried, and the solvent was evaporated. The remaining solid was crystallized from EtOAc−petroleum ether, giving 0.75 g (77%) of white plates of **8e**, X = H, mp 90−2 °C. Anal. Calcd for $C_{14}H_{11}NF_6O_5$: C, 43.42; H, 2.86; N, 3.62. Found: C, 43.41; H, 3.00; N, 3.37%. Spectral data are in Tables S34−S36.

2,2,2-Trifluoroethyl Methyl Malonate (9c). This ester was prepared according to Danieli's procedure.[26] ^{1}H NMR ($CDCl_3$) δ: 3.48 (2H, s), 3.75 (3H, s), 4.52 (2H, q, J = 8.3 Hz). No signal was observed at δ 12−20 whether at room temperature or at 240 K. ^{13}C NMR ($CDCl_3$, rt) δ: 40.54 (t, J = 133 Hz), 52.65 (q, J = 148 Hz), 60.92 (t of q, $J_{triplet}$ = 151 Hz, $J_{quartet}$ = 37 Hz,), 122.62 (q of t, $J_{quartet}$ = 277 Hz, $J_{triplet}$ = 4.8 Hz), 164.90 (m), 163.94 (m).

Reaction of 2,2,2-Trifluoroethyl Methyl Malonate with Aryl Isocyanates. The following procedure is representative also of the reaction of the *p*-Br, *p*-Me, *p*-MeO, and 2,4-$(MeO)_2$ phenyl isocyanates.

A solution of 2,2,2-trifluoroethyl methyl malonate (1 g, 5 mmol) in dry ether (10 mL) was added dropwise into a stirred mixture of sodium (0.12 g, 5.2 mmol) and ether (30 mL) during

30 min at room temperature, and the mixture was stirred overnight at room temperature. A solution of phenyl isocyanate (0.59 g, 5 mmol) in dry ether (10 mL) was added dropwise during 30 min to this solution at room temperature. The mixture was refluxed for 2 h, cooled to room temperature, filtered, and washed with ether, giving 1.7 g (99%) of the sodium salt of **8c**, X = H, as a white solid. ^{1}H NMR (DMSO-d_6, 298 K) δ: 3.46 (3H, s), 4.50 (2H, q, J = 9.4 Hz), 6.83 (1H, t), 7.17 (2H, t), 7.50 (2H, d), 10.89 (1H, s).

A solution of the crude salt (1.7 g, 5 mmol) in DMF (5 mL) was added dropwise to an ice-cooled 2 N HCl solution (50 mL) with stirring. An oil was separated at first, and it solidified later. It was filtered, washed with cold water, and dried in air, giving 1.2 g (75%) of the amide **7c**, X = H, mp 60−2 °C. Anal. Calcd for $C_{13}H_{12}F_3NO_5$: C, 48.91; H, 3.79; N, 4.39. Found: C, 48.97; H, 3.92; N, 4.38%. Spectral data are in Tables S34−S36.

Bis(2,2,2-trifluoroethyl) Malonate (9b). This ester was prepared according to a modified procedure of Raha.[27] ^{1}H NMR ($CDCl_3$, 298 K) δ: 3.57 (2H, s), 4.51 (4H, q, J = 8.3 Hz); ^{13}C NMR ($CDCl_3$, 298 K) δ: 39.98 (t, J = 133 Hz), 61.09 (t of q, $J_{triplet}$ = 152 Hz, $J_{quartet}$ = 37 Hz), 122.58 (q of t, $J_{quartet}$ = 277 Hz, $J_{triplet}$ = 47 Hz), 164.15 (m).

Reaction of Bis(2,2,2-trifluoroethyl) Malonate with Aryl Isocyanate. The reaction described below is a representative of the reaction with *p*-Br, *p*-Me, *p*-MeO, and 2,4-$(MeO)_2$ phenyl isocyanates.

To a solution of bis(2,2,2-trifluoroethyl) malonate (1.34 g, 5 mmol) and triethylamine (1.02 g, 10 mmol) in dry DMF (5 mL) which was stirred for 5 min was added phenyl isocyanate (0.59 g, 5 mmol), and the solution was stirred overnight. It was then poured into ice-cooled 2 N HCl solution (100 mL) with stirring. The mixture was extracted with EtOAc, the organic layer was washed with cold water and dried (Na_2SO_4), and the solvent was evaporated, giving 1.45 g (75%) of enol **8b**, X = H, as long white plates, mp 116−8 °C. Anal. Calcd for $C_{14}H_{11}NF_6O_5$: C, 43.42; H, 2.86; N, 3.62. Found: C, 43.07; H, 3.01; N, 3.60%. The spectral data are in Tables S34−S36.

1,1,1,3,3,3-Hexafluoroisopropyl 2,2,2-Trifluoroethyl Malonate (9d). **(a) 2,2,2-Trifluoroethyl Hydrogen Malonate.** To a solution of bis(2,2,2-trifluoroethyl) malonate (34.5 g, 0.13 mol) in 2,2,2-trifluoroethanol (15 mL) at 0−5 °C was added dropwise a solution of KOH (7.6 g, 0.14 mol) in 2,2,2-trifluoroethanol (30 mL) with stirring during 1 h. Stirring was continued for 3 h, and then the solution was kept overnight at room temperature. It was then refluxed for 30 min, and the solvent was evaporated at reduced pressure, leaving the potassium salt of 2,2,2-trifluoroethyl hydrogen malonate.

The crude potassium salt was dissolved in water (50 mL), the organic residues were extracted with ether, and concentrated HCl was added at ice−water temperature to the aqueous solution. The solution was extracted four times with methylene chloride, the organic phase was dried ($MgSO_4$), and the solvent was evaporated. The residue which stood overnight at room temperature gave 18 g (75%) of crystals of 2,2,2-trifluoroethyl hydrogen malonate. ^{1}H NMR ($CDCl_3$, 298 K) δ: 3.56 (2H, s), 4.55 (2H, q, J = 8.4 Hz), 11.24 (1H, s, OH). ^{19}F NMR ($CDCl_3$, 298K) δ: − 74.94 (t, J = 8.6 Hz). ^{13}C NMR ($CDCl_3$, 298 K) δ: 40.27 (t, J = 133 Hz). 61.02 (t of q, J_t = 152 Hz, J_q = 37 Hz), 122.59 (q of t, J_q = 277 Hz, J_t = 4.7 Hz), 164.78 (m), 171.40 (t, J = 7.5 Hz). Anal. Calcd for $C_5H_5F_3O_4$: C, 32.27; H, 2.71. Found: C, 32.35; H, 2.81%.

(b) 2,2,2-Trifluoroethyl Malonyl Chloride. A mixture of 2,2,2-trifluoroethyl hydrogen malonate (12 g, 0.064 mmol) and phthaloyl dichloride (20 g, 0.098 mol) was heated at 100−110 °C for 3 h and then distilled from an oil bath up to 165° at water pump pressure to give 4.66 g (35%) of 2,2,2-trifluoroethyl malonyl chloride, bp 90 °C. ^{1}H NMR ($CDCl_3$, 298 K) δ: 4.00 (2H, s), 4.57 (2H, q, J = 8.2 Hz). ^{13}C NMR ($CDCl_3$, 298 K) δ: 51.12 (t, J = 136 Hz), 61.33 (t of q, J_t = 152 Hz, J_q = 37 Hz), 122.39 (q of t, J_q = 277 Hz, J_t = 4.7 Hz), 162.42 (m), 165.63 (t, J = 8.3 Hz).

(c) Reaction of 2,2,2-Trifluoroethyl Malonyl Chloride with 1,1,1,3,3,3-Hexafluoro-2-propanol. A solution of 2,2,2-trifluoroethyl malonyl chloride (0.7 g, 3.4 mmol) in methylene chloride (2 mL) was added dropwise into a solution containing 1,1,1,3,3,3-hexafluoro-2-propanol (0.7 g, 4.16 mmol), *N*,*N*-dimethylaniline (0.45 g, 37 mmol), and methylene chloride (5 mL). After the addition was complete the solution was refluxed with stirring for 3 h and then left overnight at room temperature. Water (15 mL) was added, and two layers were formed. The aqueous phase was extracted once with methylene chloride, and the combined organic phase was washed with 10% sulfuric acid and dried over sodium sulfate. The solvent was evaporated at reduced pressure. The residue was distilled in a vacuum to get 0.5 g (43%) of 1,1,1,3,3,3-hexafluoroethyl 2,2,2-trifluoroethyl malonate **9d**, as a colorless liquid. ^{1}H NMR ($CDCl_3$) δ: 3.17 (2H, s), 4.53 (2H, q, J = 8.3 Hz), 5.97 (1H, heptet, J = 5.9 Hz, C*H*$(CF_3)_2$). ^{1}H NMR (CCl_4, 298K) δ: 2.88 (2H, s, CH_2), 3.74 (2H, q, J = 8.2 Hz), 4.99 (1H, heptet, J = 5.9 Hz). ^{19}F NMR ($CDCl_3$, 298K) δ: −74.40 (d, J = 6.0 Hz), −75.07 (t, J = 8.6 Hz); ^{13}C NMR ($CDCl_3$, 298K) δ: 39.67 (t, J = 134 Hz), 61.25 (t of q, J_t = 152 Hz, J_q = 37 Hz), 67.30 (d of heptet, J_d = 151 Hz, J_{heptet} = 35 Hz), 120.12 (q, J = 285 Hz), 122.44 (q of t, J_q = 277 Hz, J_t = 4.6 Hz), 162.66 (m), 163.28 (m).

The reaction was frequently accompanied by disproportionation when the ^{1}H NMR spectrum showed the presence of few percent of **9b**. Attempted separation of the two esters by chromatography had failed.

Reaction of 1,1,1,3,3,3-Hexafluoroethyl 2,2,2-Trifluoroethyl Malonate with Aryl Isocyanates. The procedure below represents also the similar procedure used for the reaction with *p*-tolyl and phenyl isocyanates.

To a solution containing 1,1,1,3,3,3-hexafluoroethyl 2,2,2-trifluoroethyl malonate (0.5 g, 1.47 mmol) and Et_3N (0.3 g, 2.9 mmol) in THF (3 mL) which was stirred at room temperature for 5 min was added *p*-methoxyphenyl isocyanate (0.2 g, 1.47 mmol), and the solution was stirred for 24 h at room temperature. It was then poured into ice-cooled 2 N HCl solution (40 mL) and extracted with EtOAc, and the organic phase was washed with water and dried ($MgSO_4$). The solvent was evaporated, leaving 0.3 g (42%) of a yellow solid, which according to the ^{1}H NMR ($CDCl_3$) spectrum contains the two enols **8d** and **8b**, X = *p*-MeO. Recrystallization from EtOAc−petroleum ether gave plates of **8d**, X = *p*-MeO, mp 85−6 °C. Anal. Calcd for $C_{16}H_{12}F_9NO_6$: C, 39.60; H, 2.49, N, 2.89. Found: C, 39.90; H, 2.66; N, 2.73%. Spectral data are in Tables S34−S36.

Bis(1,1,1,3,3,3-hexafluoroisopropyl) Malonate (9f). To a mixture of 1,1,1,3,3,3-hexafluoro-2-propanol (30 g, 0.178 mol) and *N*,*N*-dimethylaniline (15 mL, 14.34 g, 0.118 mmol) in an ice-bath cooled flask was added dropwise a solution of malonyl dichloride (5 g, 35.5 mmol) in $CaCl_2$-dried alcohol free chloroform (10 mL) from a $CaCl_2$-protected funnel. After completion of the addition (30 min), the light greenish mixture was refluxed for 4 h. The solution was cooled, ice-cooled 6 N H_2SO_4 solution (30 mL) was added with stirring, and the product was extracted thrice with ether. The combined ether extracts were washed succedingly with 6 N H_2SO_4 solution, with water, with Na_2CO_3 solution, and with a saturated NaCl solution and dried (Na_2SO_4). The ether was distilled at reduced pressure, and the residue was distilled at 54−6°/0.6 Torr, giving the yellow bis(1,1,1,3,3,3-hexafluoroisopropyl) malonate (1.2 g, 8.4%). ^{1}H NMR ($CDCl_3$) δ: 3.79 (s), 5.79 (heptet, J_{FH} = 5.8 Hz). No other signal was observed down to 20 ppm; ^{19}F NMR ($CDCl_3$, 298K) δ: −74.71 ppm (J_{HF} = 8 Hz); ^{13}C H-coupled NMR ($CDCl_3$, rt) δ: 39.50 (t, J_{CH} = 135 Hz), 67.83 (d of heptets, J_{FH} = 35 Hz, J_{CH} = 151 Hz), 119.85 (q of narrow m, J_{FC} = 284 Hz), 162.30 (heptet, J_{CH} = 4 Hz). Anal. Calcd for $C_9H_4F_{12}O_4$: C, 26.75; H, 1.00. Found: C, 26.64; H, 1.01%.

Reaction of Bis(1,1,1,3,3,3-hexafluoroisopropyl) Malonate (9a) with Phenyl Isocyanate. A mixture of bis-(1,1,1,3,3,3-hexafluoroisopropyl) malonate (0.51 g, 1.26 mmol), triethylamine (2.5 g, 2.5 mmol), and PhNCO (0.15 g, 1.26

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mmol) in DMF (4 mL) was stirred for 2 h at room temperature. The solution was poured into ice cold 2 N aqueous HCl (50 mL), and a precipitate was formed which was showed by ^{1}H NMR spectra and mixed mp to be *N*,*N*′-diphenylurea. The same result was obtained on repeated experiments.

Thermal Decomposition of 8b, Ar = Ph. A solution of **8b**, Ar = Ph (0.17 g, 0.4 mmol) in $Cl_2CHCHCl_2$ (5 mL) was heated to 100 °C for 24 h and left for additional 3 days at room temperature. The solvent was evaporated, and the residue was purified by chromatography on a silica gel column using 2:3 EtOAc:petroleum ether eluent, giving a white solid (0.07 g, 61%). Crystallization from EtOAc:petroleum ether gave crystals of anilido(2,2,2-trifluoroethoxycarbonyl)methane, mp 82−3 °C. Anal. Calcd for $C_{11}H_{10}F_3NO$: C, 50.58; H, 3.86; N, 5.36. Found: C, 50.87; H, 4.06; N, 5.13%.

^{1}H NMR ($CDCl_3$) δ: 3.59 (3H, s), 4.56 (2H, q, J = 8.2 Hz), 7.14 (1H, t, J = 7.4 Hz), 7.33 (2H, t, J = 7.9 Hz), 7.52 (2H, d, J = 7.9 Hz), 8.73 (1H, br s). ^{13}C NMR ($CDCl_3$) δ: 41.46 (t, J = 132 Hz), 61.04 (tq, J_t = 151 Hz, J_q = 37 Hz), 122.50 (qt, J_q = 279 Hz, J_t = 4.7 Hz), 120.25 (dm, J_d = 160 Hz), 124.94 (dt, J_d = 163 Hz, J_t = 7.2 Hz), 129.04 (dd, J_1 = 163 Hz, J_2 = 7.0 Hz), 137.09 (t, J = 9.9 Hz), 161.86 (t, J = 6.9 Hz), 167.91 (m).

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Supporting Information Available: General crystallographic data, and tables of bond lengths and angles, positional and thermal parameters (Tables S1−S30), Tables of the **7**/*E*-**8**/*Z*-**8** distributions (Tables S31−S33), Tables of the ^{1}H, ^{13}C, and ^{19}F NMR data of all amides/enols (Tables S34−S36), summary of crystallographic parameters (Table S37), and six stereoviews, three ORTEP's, and two NMR spectra (Figures S1−S11). Also available are CIF files of X-ray data for **8b**, Ar = Ph, *p*-Tol, *E*-**8d**, Ar = *p*-An, and *E*-**8e**, Ar = Ph, *p*-Tol, *p*-An. The material is available free of charge via the Internet at http://pubs.acs.org.

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