Reactions of 2-Unsubstituted 1*H*-Imidazole 3-Oxides with 2,2-Bis(trifluoromethyl)ethene-1,1-dicarbonitrile: A Stepwise 1,3-Dipolar Cycloaddition

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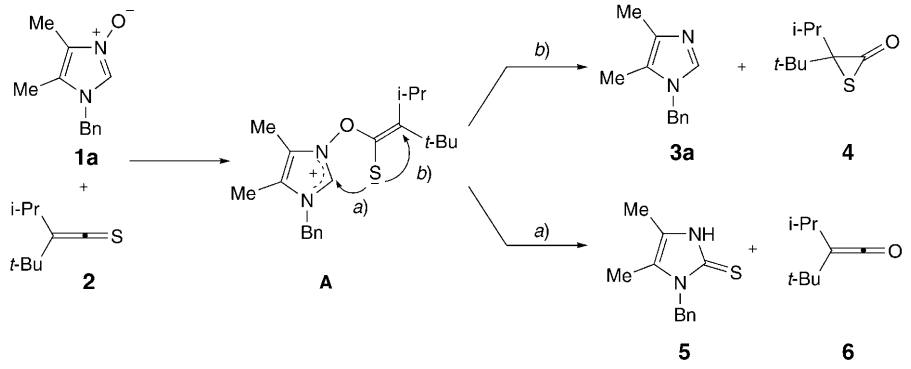
The reaction of 1,4,5-trisubstituted 1*H*-imidazole-3-oxides **1** with 2,2-bis(trifluoromethyl)ethene-1,1-dicarbonitrile (**7**, BTF) yielded the corresponding 1,3-dihydro-2*H*-imidazol-2-ones **10** and 2-(1,3-dihydro-2*H*-imidazol-2-ylidene)malononitriles **11**, respectively, depending on the solvent used. In one example, a 1:1 complex, **12**, of the 1*H*-imidazole 3-oxide and hexafluoroacetone hydrate was isolated as a second product. The formation of the products is explained by a stepwise 1,3-dipolar cycloaddition and subsequent fragmentation. The structures of **11d** and **12** were established by X-ray crystallography.

1. Introduction. – Imidazole *N*-oxides are interesting compounds with respect to their applications as building blocks in the synthesis of imidazole derivatives [1–3] and for their diverse biological activities [4–6]. Convenient syntheses of 2-unsubstituted imidazole *N*-oxides are condensations of α-(hydroxyimino) ketones with *in situ* generated formimides [7], of α-amino oximes with orthoformates [8], and of diimines with formaldoxime [9]. Generally, imidazole *N*-oxides are not available by direct oxidation of the parent compound. However, a recent paper describes the preparation of 1-methylimidazole N^3-oxide by treatment of 1-methyl-1*H*-imidazole in THF with H_2O_2 at room temperature [10]. Starting with imidazole *N*-oxides, preparations of imidazole-2-thiones [7], 2-cyanoimidazoles [11], as well as parent imidazoles *via* deoxygenation with PCl_3 [12] were reported. Furthermore, the isomerization to give imidazol-2-ones can easily be achieved by treatment with Ac_2O [11] or photochemically [13].

The structure of 2-unsubstituted imidazole *N*-oxides relates to aldonitrones, which are well-known 1,3-dipoles. In fact, they react with dipolarophiles, such as dimethyl acetylenedicarboxylate [2][12], isocyanates, and isothiocyanates [2], as well as with thioketones and thioketenes [7] to give finally products, which result from subsequent conversions of the initially formed [2+3] cycloadducts. Of special mechanistic interest is the reaction of **1a** with thioketene **2**, in which the formation of two sets of products, *i.e.*, **3a**/**4** and **5**/**6** is an indication for the stepwise reaction pathway [7] (*Scheme 1*). The reaction of the dipole **1a** with the heterocumulene **2** leads to the zwitterionic intermediate **A**, in which the formation of the five-membered unstable cycloadduct (*Route a*) competes

[1]) Part of the planned Ph.D. thesis of *M. J.,* University of Łódź.

Scheme 1

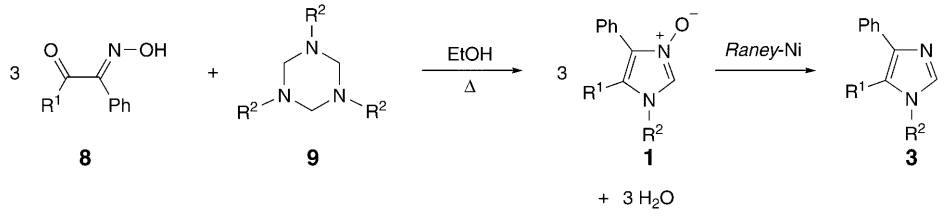


with the cyclization to yield thiirane **4** (*Route b*). Cycloreversion of the cycloadduct leads to **5** and **6**. These results prompted us to test other dipolarophiles in reactions with 1*H*-imidazole 3-oxides of type **1**. The electron-deficient 2,2-bis(trifluoromethyl)-ethene-1,1-dicarbonitrile (**7**; BTF) was selected for the present study.

Apart from the fact that **7** has been used extensively in *Diels–Alder* reactions [14] and in [2+2] cycloadditions [15], to the best of our knowledge, no [2+3] cycloadditions with this dipolarophile have been reported.

2. Results and Discussion. – According to the previously described procedure, five known and three new 1*H*-imidazole 3-oxides of type **1** were prepared by heating mixtures of α-(hydroxyimino) ketones **8** and the corresponding hexahydro-1,3,5-triazines **9**, the trimers of the corresponding formimines, in EtOH (*Scheme* 2).

Scheme 2



	1b	**1c**	**1d**	**1e**	**1f**	**1g**	**1h**	**1i**
R^1	Me	Ph	Ph	Me	Ph	Me	Me	Ph
R^2	Me	Me	Bn	cHex	cHex	cProp	Allyl	Allyl

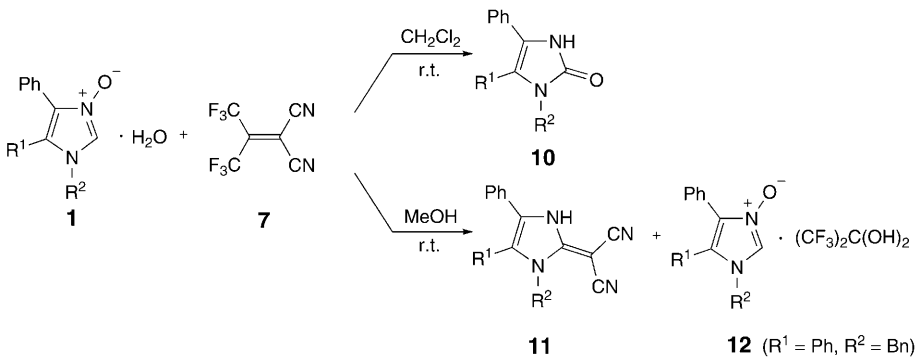
All prepared compounds **1b**–**1i** were isolated as colorless crystals, which contained variable amounts of H_2O. Removal of H_2O was neither possible by drying under reduced pressure nor by azeotropic distillation with toluene, because of the thermal instability of **1**, which was converted into the corresponding 2*H*-imidazol-2-ones. The 1*H*-imidazole 3-oxide hydrates of type **1**·H_2O showed a characteristic *singlet* at *ca.* 7.8–8.2 ppm in the ^{1}H-NMR spectra. When the spectra were recorded from a solution

in CD_3OD, the signal disappeared after several hours at room temperature (H/D exchange)[2]).

As mentioned in the *Introduction*, the transformation of *N*-oxides of type **1** into the parent imidazoles was typically carried out by treatment with PCl_3 [1][3][12]. In our laboratory, *N*-oxides **1** were deoxygenated by using freshly prepared *Raney*-Ni [16] in EtOH at room temperature, and the corresponding imidazoles were obtained in almost quantitative yield (*e.g.*, **1b** → **3b** ($R^1 = R^2 = Me$), **1d** → **3d** ($R^1 = Ph$, $R^2 = Bn$)).

The first experiments with BTF (**7**) were carried out in CH_2Cl_2 with the *N*-oxides **1** as hydrates. The conversions were completed within *ca.* 15 min at room temperature. The major product obtained in these reactions was the corresponding 1,3-dihydro-2*H*-imidazol-2-one **10** (*Scheme 3*). In addition, small amounts of (1,3-dihydro-2*H*-imidazol-2-ylidene)malononitriles **11** were detected. Carrying out the same reaction in MeOH solution, compounds **11** were formed as the main products. Fractional crystallization of the mixtures gave **11** as colorless or pale-yellow crystals. Unexpectedly, in the experiment with **1d**, in addition to **11d**, the complex of the starting material with hexafluoroacetone hydrate, depicted as structure **12** in *Scheme 3*, was isolated by concentration of the mother liquor and recrystallization of the residue from CH_2Cl_2.

Scheme 3



1,3-Dihydro-2*H*-imidazol-2-ones of type **10** are well documented compounds, and the identification of **10b**–**10i** was possible on the basis of their spectroscopic and analytical data as well as by comparison with original samples. The malononitrile derivatives **11** are less well known. Their IR spectra (KBr) show two intense absorption bands of the CN groups located at *ca.* 2195 and 2155 cm^{-1}. In the ^{13}C-NMR spectra ((D_6)DMSO or $CDCl_3$), the C-atoms of the exocyclic formal C=C bond absorb at 148–146 ppm (C(2)) and 26–23 ppm ($=C(CN)_2$), which is characteristic of this type of 'push-pull' system [17][18]. These chemical shifts indicate a highly zwitterionic character of these compounds in solution, resulting in a low rotational barrier about the exocyclic $C=(CN)_2$ bond [17]. In accordance with this interpretation is the fact that only one CN signal appears in the ^{13}C-NMR spectrum. In the case of **12**, the IR spec-

[2]) Very fast H/D exchange was observed in basic aqueous solution, whereas it was slow in the presence of DCl [8].

trum showed the presence of a series of strong and broad absorption bands between 3400 and 2374 cm^{-1}, which were attributed to the associated O–H bonds. Another strong absorption at 1213 cm^{-1} revealed the presence of the CF_3 group. In the ^{1}H-NMR spectrum recorded from a solution in CD_3OD, the characteristic signal of H–C(2) of the imidazole ring occurred at 8.48 ppm and was downfield-shifted compared with the corresponding signal in **1d**.

Finally, the molecular structures of **11d** and **12** were established by single-crystal X-ray diffraction analysis (*Figs. 1* and *2*).

The asymmetric unit in the structure of **11d** contains one molecule of the heterocycle plus one highly disordered MeOH molecule. The disorder of the MeOH molecule could not be modelled adequately. Therefore, the contribution of the solvent molecules to the intensity data was removed by using the SQEEZE [20] routine of the PLATON program [21]. The NH group of **11d** forms an intermolecular H-bond with the N-atom of one of the CN groups of a neighboring molecule. In turn, the acceptor molecule donates the same type of H-bond back to the original molecule, therefore, forming centrosymmetric dimers where the H-bonds form a closed loop with a graph set motif [22] of $R_2^2(12)$. The five-membered heterocycle is almost planar, and the adjacent atoms C(13), C(16), and C(22) deviate only slightly from this plane. The intraannular C,N-

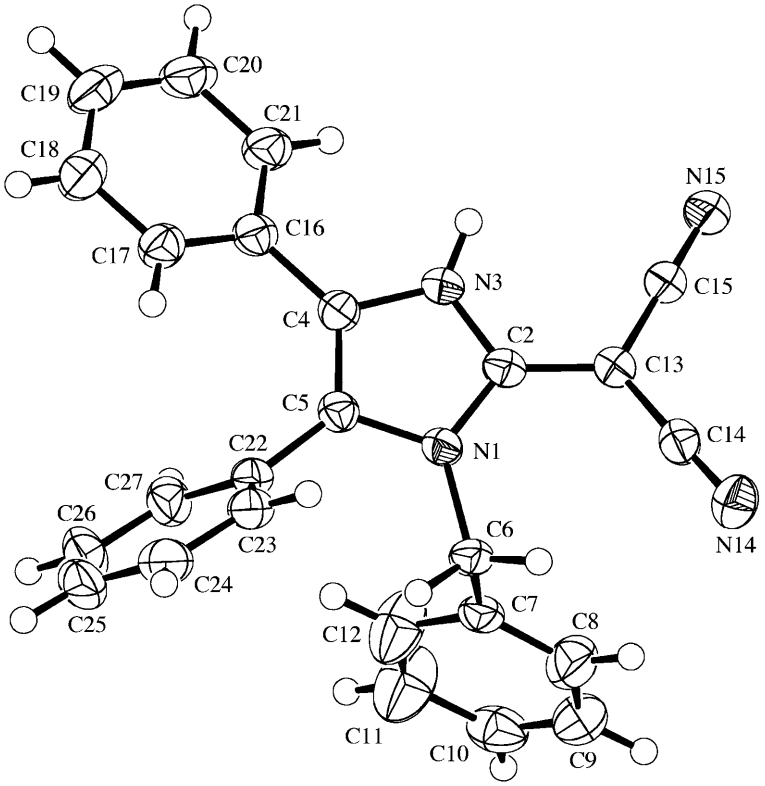


Fig. 1. *ORTEP Plot* [19] *of the molecular structure of* **11d** (arbitrary numbering of the atoms; 50% probability ellipsoids)

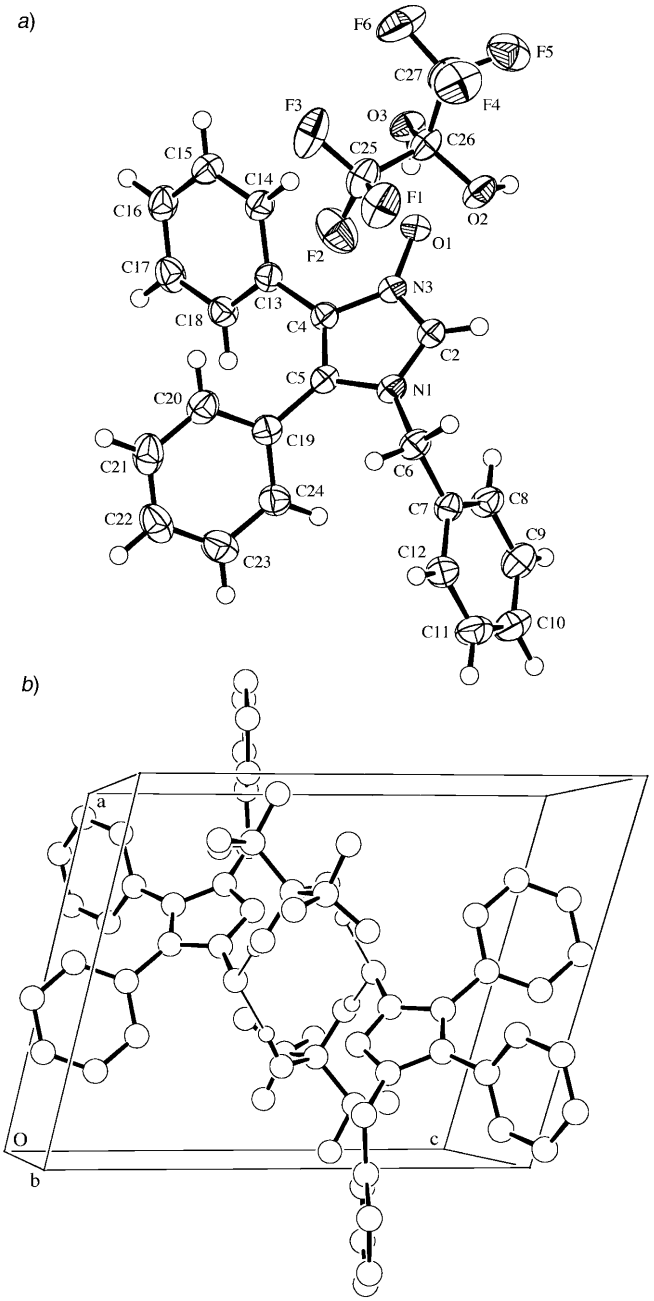
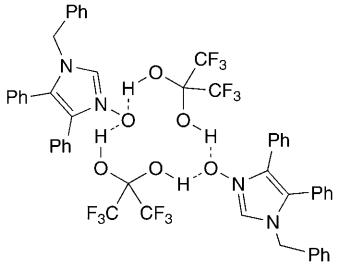


Fig. 2. a) *ORTEP Plot* [19] *of the molecular structure of* **12** (arbitrary numbering of the atoms; 50% probability ellipsoids) *and* b) *packing diagram*

bonds (N1),C(2) and N(3),C(2)) are short (1.349(2) and 1.346(2) Å, resp.); the bond lengths are close to those of C=N bonds (*ca.* 1.30 Å). Similarly, the C,C-bonds to the C≡N groups, *i.e.*, C(13),C(14) and C(13),C(15), show significant double-bond character (1.406(2) and 1.408(2) Å, resp.). On the other hand, the formal C(2),C(13) double-bond is rather long (1.426(2) Å). These data support a zwitterionic structure with the positive charge delocalized between N(1),C(2), and N(3), and the negative one between CN(14), C(13), and CN(15). Surprisingly, the plane of the malonodinitrile moiety is twisted only slightly out of the heterocyclic plane (dihedral angle N(1)–C(2)–C(13)–C(14) = –15.7°).

There is one molecule of the zwitterionic oxide and one molecule of hexafluoropropane-2,2-diol (hexafluoroacetone hydrate) in the asymmetric unit of structure **12**. The OH groups form intermolecular H-bonds with the oxide O-atom of two different zwitterions, so that each zwitterion accepts a H-bond at the same atom from two different ketone hydrates. These interactions together link two zwitterions and two ketone hydrates to give centrosymmmetric tetramers where the H-bonds form a closed loop with a graph set motif of $R_4^2(12)$.

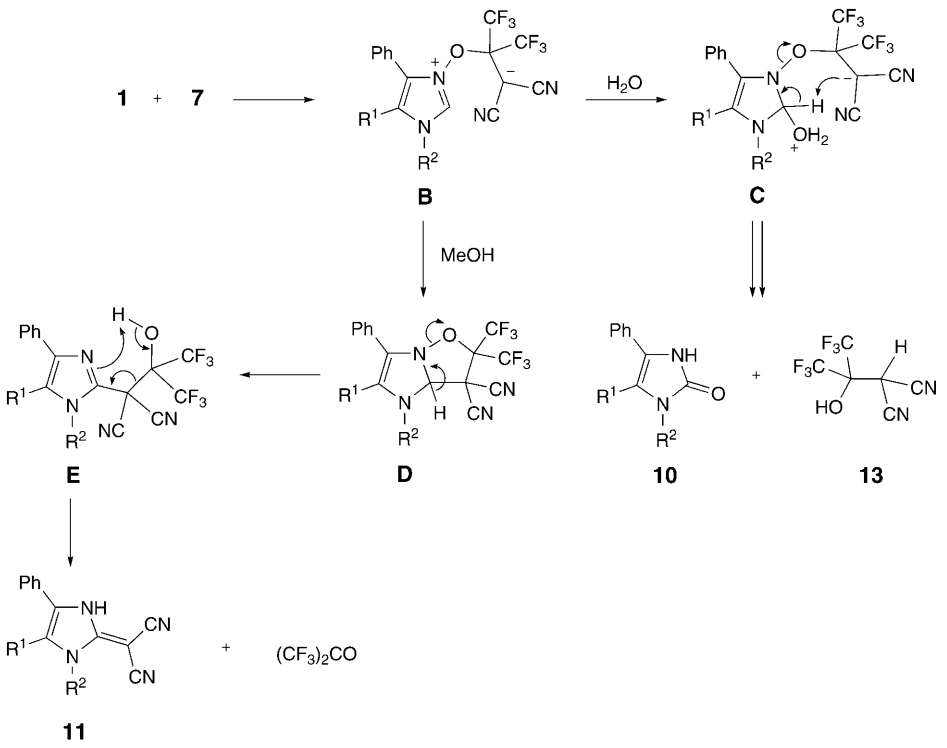


Reaction mechanisms for the formation of the imidazole derivatives **10** and **11** are proposed in *Scheme 4.* The key intermediate is the zwitterion **B**, which is formed by a nucleophilic addition of **1** onto **7**. In CH_2Cl_2, **B** reacts with the H_2O of the hydrate to give **C**, which undergoes a subsequent fragmentation to yield **10**. As the second product, we postulate the adduct **13** of H_2O and **7**, which, however, could not be detected after workup. The conversion of **B** to **11** in MeOH solution occurs *via* a 1,5-dipolar electrocyclization, which yields the 'cycloadduct' **D**. Subsequent cleavage of the N–O bond, followed by a retro-ene reaction finally leads to **11** and hexafluoroacetone, which is immediately captured by H_2O. The different reaction course in CH_2Cl_2 and in MeOH is remarkable. A likely interpretation is the higher nucleophilicity of H_2O in an aprotic solvent like CH_2Cl_2 compared with MeOH, which reduces the nucleophilicity by solvation.

As shown in *Scheme 4*, H_2O plays an important role in the formation of products in the reaction of **1** and **7**. For this reason, the reaction was repeated with anhydrous *N*-oxides **1**, which were prepared by drying the corresponding hydrates with activated molecular sieves in $CHCl_3$. Under these conditions, the (1,3-dihydro-2*H*-imidazol-2-ylidene)malononitriles **11** were formed in high yield (*Scheme 4*). Neither 1,3-dihydro-2*H*-imidazol-2-ones **10** nor complexes of type **12** were present in the reaction mixtures.

In conclusion, the present study shows that 1*H*-imidazole 3-oxides **1** easily react with BTF (**7**). Although the formation of products **11** can be explained by a formal

Scheme 4



[2+3] cycloaddition to give **D** the formation of 1,3-dihydro-2*H*-imidazol-2-ones **10** (in the reaction involving H_2O) clearly indicate a stepwise reaction mechanism. The common intermediate in the formation of all products is the zwitterion **B**, which is the product of the regioselective attack of the 'nitrone-like' dipolar species **1** on **7**. This reaction can be regarded as the initial step of a *Michael* addition, thus leading to the activation of C(2) of the imidazolium ring. In the light of these results, the combination **1**/**7** fulfils the fundamental requirement for a stepwise course of a [2+3] cycloaddition, *i.e.*, an electron-rich 1,3-dipole approaches an electron deficient dipolarophile [23][24].

The formation of **11** under anhydrous conditions can be of preparative importance as derivatives of (1,3-dihydro-2*H*-imidazol-2-ylidene)malononitriles are known as pharmacologically active compounds [25].

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Experimental Part

1. *General.* M.p.: *Melt-Temp. II* apparatus (*Aldrich*); in capillaries; uncorrected. IR Spectra (KBr): *NEXUS FT-IR* spectrophotometer; in KBr. ^{1}H- and ^{13}C-NMR spectra: *Tesla BS567A* (80 and 20 MHz, resp.) or *Bruker AC 300* instrument (300 and 75.5 MHz, resp.); in $CDCl_3$, TMS as an internal standard.

The multiplicity of the ^{13}C-NMR signals was deduced from the DEPT spectra. MS (EI or CI): *Finnigan MAT-90* or *Finnigan SSQ-700* instruments. Elemental analyses were performed in the Analytical Laboratory of the University of Zürich or in the Laboratory of the Polish Academy of Sciences (CBMiMM) in Łódź.

2. *Starting Materials.* α-(Hydroxyimino) ketones **8** were obtained according to known protocols: R^1 = Me [26], R^1 = Ph [27]. 1,3,5-Trisubstituted hexahydro-1,3,5-trizines **9** were prepared according to known methods: R^2 = Me [28], R^2 = Bn [29], R^2 = cHex (cyclohexyl) [30], R^2 = cPr (cyclopropyl) [31], and R^2 = allyl [32].

3. *Preparation of 1*H-*Imidazole 3-Oxides* (**1**): Syntheses and properties of the *N*-oxides **1b**–**1f** have already been described [7][11][33]. Compounds **1g**–**1i**, which have not been described so far, were prepared by heating 1.2 mmol of the corresponding 1,3,5-hexahydrotriazine **9** with 1.0 mmol of 3-(hydroxyimino)-3-phenylpropan-2-one (**8**, R^1 = Me) and α-benzil monoxime (**8**, R^1 = Ph), respectively, in boiling EtOH. After removal of the solvent *in vacuo*, the resulting mixture was treated with Et_2O, cooled, then the product was filtered, washed with cold acetone, and recrystallized. In the case of *1-allyl-4,5-diphenyl-1*H-*imidazole 3-oxide* (**1i**), the mixture also contained the isomeric 1,3-dihydro-2*H*-imidazol-2-one, which was formed as a side product, and the separation of both compounds was achieved by column chromatography (SiO_2; AcOEt).

*1-Cyclopropyl-5-methyl-4-phenyl-1*H-*imidazole 3-Oxide* (**1g**): 3 h; yield: 199 mg (93%). Colorless needles. M.p. 172–174° (acetone). IR: 3063*s*, 3020*m*, 2961*s* (br.), 1619*m* (br.), 1594*m*, 1497*m*, 1445*m*, 1422*s*, 1386v*s*, 1374v*s*, 1317*m*, 1258*m*, 1219*s*, 1150*m*, 1064*w*, 1036*m*, 894*m*, 843*m*, 825*s*, 769*m*, 755*s*, 697*s* (br.). ^{1}H-NMR: 7.27 (*s*, H–C(2)); 6.78–6.76, 6.60–6.47 (2*m*, 5 arom. H); 2.36–2.31 (*m*, 1 H of cPr); 1.50 (*s*, Me); 0.29–0.15 (*m*, 4 H of cPr). ^{13}C-NMR: 129.9, 127.0, 124.4 (3*s*, arom. C_q, C(4), C(5)); 129.4, 128.2, 128.1 (3*d*, 5 arom. CH); 125.6 (*d*, C(2)); 27.0 (*d*, CH of cPr); 9.7 (*q*, Me); 6.4 (*t*, 2 CH_2 of cPr). EI-MS: 214 (100, $M^{+\cdot}$), 198 (62), 197 (67), 130 (30). Anal. calc. for $C_{13}H_{14}N_2O \cdot {}^1/_8\, H_2O$ (216.52): C 72.12, H 6.63, N 12.94; found: C 72.09, H 6.57, N 12.93.

*5-Methyl-4-phenyl-1-(prop-2-enyl)-1*H-*imidazole 3-Oxide* (**1h**): 2 h; yield: 191 mg (89%). Colorless crystals. M.p. 164–167° (CH_2Cl_2/Et_2O). IR: 3093*w*, 3063*s*, 3031*m*, 2980*s*, 2940v*s*, 1640*m*, 1626*m*, 1497*m*, 1456*m*, 1428*s*, 1384v*s*, 1361*m*, 1348*m*, 1317*m*, 1268*s*, 1220*s*, 1142*w*, 932*s*, 852*m*, 836*m*, 762*s*, 719*s*, 699*s*. ^{1}H-NMR: 7.91 (*s*, H–C(2)); 7.68–7.31 (*m*, 5 arom. H); 5.97–5.84 (*m*, –CH=); 5.35–5.12 (*m*, =CH_2); 4.48–4.46 (*m*, CH_2N); 2.23 (*s*, Me). ^{13}C-NMR: 131.3 (*d*, –CH=); 130.5, 127.4, 122.5 (3*s*, arom. C_q, C(4), C(5)); 129.7, 128.4, 128.2 (3*d*, 5 arom. CH); 124.9 (*d*, C(2)); 119.1 (*t*, =CH_2); 48.0 (*t*, CH_2); 9.3 (*q*, Me). CI-MS: 215 (100, $[M+1]^+$), 199 (39). Anal. calc. for $C_{13}H_{14}N_2O$ (214.27): C 72.87, H 6.59, N 13.07; found: C 72.68, H 6.57, N 13.09.

*4,5-Diphenyl-1-(prop-2-enyl)-1*H-*imidazole 3-Oxide* (**1i**): 5 h; yield: 201 mg (73%). Colorless solid. M.p. 176–180° (CH_2Cl_2/Et_2O). IR: 3065*s*, 3024*m*, 2991*s*, 2975*s*, 2935*m*, 1621*m* (br.), 1603*m*, 1585*m*, 1585*m*, 1507*m*, 1483*s*, 1458*m*, 1445*s*, 1423*m*, 1328*s*, 1344*s*, 1320*m*, 1306*m*, 1269*m*, 1208*m*, 1183*m*, 1077*m*, 1051*m*, 1024*m*, 993*m*, 955*m*, 944*m*, 930*m*, 814*m*, 769v*s*, 715v*s*, 704v*s*, 698v*s*. ^{1}H-NMR: 8.07 (*s*, H–C(2)); 7.58–7.24 (*m*, 10 arom. H); 5.93–5.80 (*m*, –CH=); 5.33–5.15 (*m*, =CH_2); 4.42–4.40 (*m*, CH_2N). ^{13}C-NMR: 131.7 (*d*, –CH=); 130.7, 129.6, 129.1, 128.1 (4*d*, 10 arom. CH); 130.8, 127.4, 127.1, 127.0 (4*s*, 2 arom. C_q, C(4), C(5)); 125.8 (*d*, C(2)); 119.6 (*t*, =CH_2); 48.3 (*t*, CH_2). CI-MS: 277 (63, $[M+1]^+$), 261 (100). Anal. calc. for $C_{18}H_{16}N_2O$ (276.34): C 78.24, H 5.84, N 10.14; found: C 78.10, H 5.85, N 10.11.

3. *Deoxygenation of 1*H-*Imidazole 3-Oxides* **1** *with* Raney-*Ni*. *General Procedure.* To a magnetically stirred soln. of **1b** (188 mg, 1.0 mmol) in EtOH (2 ml), a suspension of freshly prepared *Raney*-Ni [16] in EtOH was added portionwise in intervals of *ca.* 10 min, until the conversion of the starting material was complete (TLC). Then, the mixture was filtered in order to remove the black Ni precipitate, and the filtrate was evaporated to dryness. Imidazole **3b** was obtained as pure material (^{1}H-NMR). Analogous treatment of **1d** with *Raney*-Ni at r.t. yielded pure **3d**.

*1,5-Dimethyl-4-phenyl-1*H-*imidazole* (**3b**): Yield: 165 mg (96%). Colorless oil [34]. IR (neat): 3150–2850*m* (br.), 1717*m*, 1663*m*, 1604*s*, 1580*m*, 1563*w*, 1508*s*, 1495*s*, 1472*m*, 1444*s*, 1423*m*, 1379*s*, 1320*w*, 1303*w*, 1239*s*, 1165*m*, 1138*m*, 1071*m*, 1012*m*, 939*m*, 772*s*, 739*m*, 703*s*, 632*s*. ^{1}H-NMR: 7.73–7.10 (*m*, H–C(2), 5 arom. H); 3.57 (*s*, MeN); 2.38 (*s*, Me).

*1-Benzyl-4,5-diphenyl-1*H-*imidazole* (**3d**): Yield: 300 mg (97%). Colorless solid. M.p. 112–115° ([35]: 113–115°). IR: 3150–2950*m* (br.), 1602*s*, 1506*s*, 1497*s*, 1477*m*, 1455*s*, 1443*s*, 1433*m*, 1359*s*, 1254*s*, 1193*m*, 1068*m*, 1027*m*, 955*s*, 915*m*, 828*m*, 794*s*, 774*s*, 760v*s*, 724v*s*, 698v*s*, 668*m*, 654*s*. ^{1}H-NMR: 7.81 (*s*, H–C(2)); 7.67–6.75 (*m*, 15 arom. H); 4.98 (*s*, PhCH_2).

4. *Synthesis of 1,3-Dihydro-*2H-*imidazol-2-ones* (**10**). *General Procedure.* To a magnetically stirred soln. of 1.0 mmol 1*H*-imidazole 3-oxide **1** (hydrates with variable amounts of H_2O) in *ca.* 10 ml of CH_2Cl_2, a soln. of *2,2-bis(trifluoromethyl)ethene-1,1-dicarbonitrile* (**7**, BTF) (235 mg, 1.1 mmol) in CH_2Cl_2 (4 ml) was added dropwise at r.t., and stirring was continued for 20 min. Then, the solvent was evaporated and the semi-solid residue was triturated with Et_2O to give a colorless, crystalline material, which was identified as **10**, contaminated with traces of the corresponding **11**. Purification of the main product was achieved by crystallization from MeOH or from a mixture of hexane and CH_2Cl_2.

*1,3-Dihydro-1,5-dimethyl-4-phenyl-2*H-*imidazol-2-one* (**10b**). Yield: 118 mg (63%). Colorless crystals. M.p. (decomp.) 246–249° (MeOH; [11]: 246–251°). IR: 3200–2800*m* (br., NH), 1675v*s* (C=O), 1599*m*, 1503*m*, 1468*m*, 1434*m*, 1396*m*, 1384*m*, 845*m*, 766*m*, 745*m*, 700*m*, 666*m*. ^{1}H-NMR (CD_3OD): 7.48–7.15 (*m*, 5 arom. H); 3.22 (*s*, MeN); 2.21 (*s*, Me).

*1,3-Dihydro-1-methyl-4,5-diphenyl-2*H-*imidazol-2-one* (**10c**). Yield: 182 mg (73%). Colorless crystals. M.p. (dec.) 284–287° (MeOH; [11]: 286–290°). IR: 3200–2640*m* (br. NH); 1679v*s* (C=O); 1604*s*, 1507*s*, 1455*s*, 1432*m*, 1390*s*, 1024*m*, 955*m*, 866*m*, 834*m*, 768*s*, 746*m*, 723*m*, 698*s*, 668*m*. ^{1}H-NMR: 9.53 (br. *s*, NH); 7.55–7.25 (*m*, 5 arom. H); 7.16 (br. *s*, 5 arom. H); 3.14 (*s*, Me).

*1-Benzyl-1,3-dihydro-4,5-diphenyl-2*H-*imidazol-2-one* (**10d**). Yield: 257 mg (79%). Colorless crystals. M.p. (dec.) 221–226° (MeOH; [31]: 176–178°). IR: 3200–2800*s* (br., NH), 1686v*s* (C=O), 1604*m*, 1508*m*, 1497*m*, 1445*s*, 1400*s*, 1345*m*, 1075*w*, 935*w*, 769*s*, 746*m*, 720*m*, 696*s*, 667*m*. ^{1}H-NMR (CD_3OD): 7.36–6.87 (*m*, 10 arom. H); 7.17 (br. *s*, 5 arom. H); 4.78 (*s*, CH_2N).

*1-Cyclohexyl-1,3-dihydro-4,5-diphenyl-2*H-*imidazol-2-one* (**10f**). Yield: 229 mg (72%). Colorless crystals. M.p. (dec.) 287–290° (EtOH; [11]: 286–290°). IR: 3200–2800*s* (br., NH), 1674v*s* (C=O), 1603*m*, 1507*m*, 1444*m* (br.), 1375*s*, 1351*m*, 800*m*, 763*s*, 752*m*, 702*s*, 692*s*, 666*m*. ^{1}H-NMR (CD_3OD): 7.58–7.24 (*m*, 5 arom. H); 7.12 (br. *s*, 5 arom. H); 3.65–3.43 (*m*, 1 H of cHex); 2.55–0.80 (*m*, 10 H of cHex).

*1-Cyclopropyl-1,3-dihydro-5-methyl-4-phenyl-2*H-*imidazol-2-one* (**10g**). Yield: 154 mg (72%). Colorless crystals. M.p. (dec.) 198–200° (CH_2Cl_2/hexane). IR: 3150–2750*m* (br., NH), 1679v*s* (C=O), 1642*m*, 1602*m*, 1504*m*, 1456*m*, 1414*m*, 1374*m*, 1032*m*, 835*m*, 763*s*, 747*s*, 698*m*. ^{1}H-NMR: 9.62 (br. *s*, NH); 7.43–7.22 (*m*, 5 arom. H); 2.74–2.67 (*m*, 1 H of cPr); 2.32 (*s*, Me); 1.04–1.01 (*m*, 4 H of cPr). ^{13}C-NMR: 154.8 (*s*, C=O); 130.5, 117.7, 117.2 (3*s*, arom. C_q, C(4), C(5)); 128.8, 126.7, 126.1 (3*d*, 5 arom. CH); 22.9 (*d*, CH of cPr); 10.3 (*q*, Me); 6.7 (*t*, 2 CH_2 of cPr). CI-MS: 216 (14), 215 (100, $[M+1]^+$), 214 (5, $M^{+\bullet}$). Anal. calc. for $C_{13}H_{14}N_2O$ (214.27): C 72.87, H 6.59, N 13.07; found: C 71.75, H 6.09, N 12.72.

*1,3-Dihydro-5-methyl-4-phenyl-1-(prop-2-enyl)-2*H-*imidazol-2-one* (**10h**). Yield: 141 mg (66%). Colorless crystals. M.p. (dec.) 183–184° (MeOH). IR: 3200–2650*m* (br., NH), 1694v*s* (C=O), 1640*s*, 1599*m*, 1503*m*, 1458*m*, 1430*m*, 1408*s*, 1386*m*, 1345*m*, 937*m*, 923*m*, 843*m*, 764*s*, 741*s*, 701*m*, 669*m*. ^{1}H-NMR: 10.68 (br. *s*, NH); 7.44–7.20 (*m*, 5 arom. H); 5.98–5.85 (*m*, –CH=); 5.20–5.09 (*m*, $=CH_2$); 4.35–4.32 (*m*, CH_2); 2.22 (*s*, Me). ^{13}C-NMR: 154.1 (*s*, C=O); 133.4 (*d*, –CH=); 128.7, 126.5, 126.0 (3*d*, 5 arom. CH); 130.4, 117.8, 115.8 (3*s*, arom. C_q, C(4), C(5)); 116.2 (*t*, $=CH_2$); 42.8 (*t*, CH_2); 9.7 (*q*, Me). CI-MS: 215 (100, $[M+1]^+$), 214 (5, $M^{+\bullet}$), 188.2 (8). Anal. calc. for $C_{13}H_{14}N_2O$ (214.27): C 72.87, H 6.59, N 13.07; found: C 72.87, H 6.53, N 12.98.

*1,3-Dihydro-4,5-diphenyl-1-(prop-2-enyl)-2*H-*imidazol-2-one* (**10i**): Yield: 226 mg (82%). Colorless crystals. M.p. (dec.) 218–221° (MeOH). IR: 3200–2800*m* (br., NH), 1682v*s* (C=O), 1647*m*, 1571*m*, 1507*w*, 1444*w*, 1430*w*, 1394*m*, 1370*w*, 1358*w*, 1143*w*, 939*w*, 921*w*, 768*m* (br.), 705*m*, 694*m*, 667*m*. ^{1}H-NMR ((D$_6$)DMSO): 10.84 (br. *s*, NH); 7.51–7.20 (*m*, 10 arom. H); 5.79–5.66 (*m*, –CH=); 5.07–4.82 (*m*, $=CH_2$); 4.10–4.05 (*m*, CH_2N). ^{13}C-NMR: 152.8 (*s*, C=O); 133.8 (*d*, –CH=); 130.5, 128.8, 128.7, 128.2, 126.4, 125.3 (6*d*, 10 arom. CH); 129.5, 120.3, 117.2 (3*s*, 2 arom. C_q, C(4), C(5)); 115.7 (*t*, $=CH_2$); 42.3 (*t*, CH_2). CI-MS: 277 (100, $[M+1]^+$), 276 (18), 235 (5). Anal. calc. for $C_{18}H_{16}N_2O$ (276.34): C 78.24, H 5.84, N 10.14; found: C 77.89, H 5.76, N 10.15.

5. *Synthesis of 2-(1,3-Dihydro-2*H*-imidazol-2-ylidene)propanedinitrile* (**11**). *General Procedure.* To a stirred soln. of 1.0 mmol 1*H*-imidazole 3-oxide **1** (anh. form, obtained by drying over freshly activated molecular sieves (4 Å)) in *ca.* 10 ml of dry $CHCl_3$, a soln. of **7** (235 mg, 1.1 mmol) in $CHCl_3$ (3 ml) was added dropwise at r.t., and stirring was continued for 20 min. The solvent was evaporated *i.v.*, and the residue was triturated with *ca*. 3 ml of Et_2O. The colorless solid was filtered and purified by recrystallization from MeOH.

*2-(1,3-Dihydro-1,5-dimethyl-4-phenyl-2*H*-imidazol-2-ylidene)propanedinitrile* (**11b**). Yield: 111 mg (47%). Pale violet crystals. M.p. (dec.) 219–223° (MeOH). IR: 3250–2800*s* (br., NH), 2198v*s* (CN), 2157v*s* (CN), 1640*m*, 1589v*s* (C=C(CN)$_2$), 1503*m*, 1488*s*, 1442*m*, 1421*m*, 1218*w*, 1141*w*, 767*s*, 697*s*. ^{1}H-NMR ((D$_6$)DMSO): 7.48 (br. *s*, 5 arom. H); 3.57 (*s*, MeN); 2.24 (*s*, Me). ^{13}C-NMR ((D$_6$)DMSO): 146.1 (*s*, *C*=C(CN)$_2$); 128.6, 128.2, 127.9 (3*d*, 5 arom. CH); 124.7 124.1 (2*s*, arom. C$_q$, C(4), C(5)); 120.3 (*s*, C=C(*C*N)$_2$); 31.5 (*q*, MeN); 22.4 (*s*, C=*C*(CN)$_2$); 9.0 (*q*, Me). EI-MS: 236 (100, $M^{+\cdot}$), 221 (27), 196 (69), 130 (23), 77 (24).

*2-(1-Benzyl-1,3-dihydro-4,5-diphenyl-2*H*-imidazol-2-ylidene)propanedinitrile* (**11d**). Yield: 182 mg (49%). Pale yellow crystals. M.p. (dec.) 198–203° (MeOH). IR: 3200–2800*m* (br., NH), 2198v*s* (CN), 2164v*s* (CN), 1640*m*, 1597*m*, 1580v*s* (C=C(CN)$_2$), 1506*w*, 1497*w*, 1470*m*, 1452*m*, 1431*m*, 1344*w* (br.), 1227*w*, 769*m*, 731*m*, 698*s*. ^{1}H-NMR: 11.28 (br. *s*, NH); 7.47–6.96 (*m*, 10 arom. H); 7.25 (br. *s*, 5 arom. H); 5.23 (*s*, CH$_2$). ^{13}C-NMR: 148.4 (*s*, *C*=C(CN)$_2$); 135.1 (*s*, arom. C$_q$); 131.0, 130.0, 129.2, 128.7, 128.6, 127.9, 127.1, 126.4 (8*d*, 15 arom. CH); 127.7, 126.7, 126.6, 126.5 (4*s*, 2 arom. C$_q$, C(4), C(5)); 119.5 (*s*, C=C(*C*N)$_2$); 47.6 (*t*, CH$_2$); 26.7 (*s*, C=*C*(CN)$_2$). CI-MS: 376 (29), 375 (100, $[M+1]^+$), 285 (9).

Suitable crystals for the X-ray crystal-structure determination of **11d** were obtained from MeOH by slow evaporation of the solvent.

*2-(1-Cyclohexyl-1,3-dihydro-5-methyl-4-phenyl-2*H*-imidazol-2-ylidene)propanedinitrile* (**11e**). Yield: 133 mg (44%). Colorless needles. M.p. (dec.) 255–256° (MeOH). IR: 3200–2850*s* (br., NH), 2196v*s* (CN), 2156v*s* (CN), 1645*m*, 1599*m*, 1570v*s* (C=C(CN)$_2$), 1496*w*, 1457*m*, 1439*m*, 1340*w*, 1273*w*, 1237*w*, 818*w*, 769*m*, 701*m*. ^{1}H-NMR ((D$_6$)DMSO): 7.47 (br. *s*, 5 arom. H); 4.49–4.35 (*m*, 1 H of cHex); 2.36 (*s*, Me); 2.06–1.85, 1.70–1.62, 1.41–1.19 (3*m*, 10 H of cHex). ^{13}C-NMR ((D$_6$)DMSO): 146.0 (*s*, *C*=C(CN)$_2$); 128.5, 128.4 (2*d*, 5 arom. CH); 127.6, 126.8, 123.3 (3*s*, arom. C$_q$, C(4), C(5)); 120.9 (*s*, C=C(*C*N)$_2$); 57.7 (*d*, CH of cHex); 30.7, 25.7, 21.2 (3*t*, 5 CH$_2$ of cHex); 24.3 (*s*, C=*C*(CN)$_2$); 11.4 (*q*, Me). EI-MS: 304 (11, $M^{+\cdot}$), 222 (100), 197 (10), 77 (18), 55 (33).

*2-(1-Cyclohexyl-1,3-dihydro-4,5-diphenyl-2*H*-imidazol-2-ylidene)propanedinitrile* (**11f**). Yield: 193 mg (53%). Colorless crystals. M.p. (dec.) 278–285° (MeOH). IR: 3250–2800*s* (br., NH), 2198v*s* (CN), 2161v*s* (CN), 1636*m*, 1596*s*, 1572v*s* (*C*=*C*(CN)$_2$), 1504*m*, 1451*s*, 1435*s*, 1407*m*, 1336*w*, 1226*w*, 1224*m*, 1111*w*, 1074*w*, 1018*w*, 894*w*, 792*m*, 773*s*, 749*m*, 700v*s*. ^{1}H-NMR: 7.55–7.07 (*m*, 10 arom. H); 4.43–4.33 (*m*, 1 H of cHex); 1.95–0.77 (*m*, 10 H of cHex). ^{13}C-NMR: 148.8 (*s*, *C*=C(CN)$_2$); 133.1, 131.3, 130.2, 129.8, 128.6 (5*d*, 10 arom. CH); 132.6, 130.0, 128.9, 127.0 (4*s*, 2 arom. C$_q$, C(4), C(5)); 122.5 (*s*, C=C(*C*N)$_2$); 61.3 (*d*, CH of cHex); 33.9, 27.2, 25.9 (3*t*, 5 CH$_2$ of cHex); 24.8 (*s*, C=*C*(CN)$_2$). CI-MS: 368 (28), 367 (100, $[M+1]^+$), 342 (6), 319 (5). Anal. calc. for $C_{24}H_{22}N_4$ (366.47): C 78.66, H 6.05, N 15.29; found: C 78.37, H 6.02, N 15.25.

*2-(1-Cyclopropyl-1,3-dihydro-5-methyl-4-phenyl-2*H*-imidazol-2-ylidene)propanedinitrile* (**11g**). Yield: 120 mg (46%). Pale yellow crystals. M.p. (dec.) 241–244° (MeOH). IR: 3250–2850*s* (br., NH), 2193v*s* (CN), 2155v*s* (CN), 1647*m*, 1603*m*, 1575v*s* (C=C(CN)$_2$), 1503*s*, 1473*m*, 1447*m*, 1435*m*, 1416*m*, 1369*m*, 1330*w* (br.), 1229*w*, 1107*w*, 1038*m*, 1012*w*, 843*m*, 769*s*, 742*m*, 710*m*, 696*s*, 666*m*. ^{1}H-NMR ((D$_6$)DMSO): 7.49–7.44 (*m*, 5 arom. H); 3.18–3.12 (*m*, 1 H of cPr); 2.31 (*s*, Me); 1.22–1.09 (2*m*, 4 H of cPr). ^{13}C-NMR ((D$_6$)DMSO): 148.3 (*s*, *C*=C(CN)$_2$); 128.5, 128.1, 127.9 (3*d*, 5 arom. CH); 127.8, 125.1, 124.6 (3*s*, arom. C$_q$, C(4), C(5)); 120.3 (*s*, C=C(*C*N)$_2$); 26.5 (*s*, C=*C*(CN)$_2$); 24.1 (*d*, CH of cPr); 10.2 (*q*, Me); 10.1 (*t*, 2 CH$_2$ of cPr). EI-MS: 262 (67, $M^{+\cdot}$), 222 (35), 221 (100), 130 (28), 103 (20), 77 (24).

*2-(1,3-Dihydro-5-methyl-4-phenyl-1-(prop-2-enyl)-2*H*-imidazol-2-ylidene)propanedinitrile* (**11h**). Yield: 160 mg (61%). Colorless crystals. M.p. (dec.) 200–205° (MeOH). IR: 3250–2850*s* (br., NH), 2194v*s* (CN), 2153v*s* (CN), 1646*s*, 1579v*s* (C=C(CN)$_2$), 1504*s*, 1475*s*, 1444*m*, 1433*m*, 1414*m*, 1320*m*, 1288*w*, 1272*w*, 1229*w*, 1154*w* (br.), 988*m*, 934*m*, 923*w*, 791*m*, 769*s*, 698*s*. ^{1}H-NMR ((D$_6$)DMSO): 12.75 (br. *s*, NH); 7.49–7.37 (*m*, 5 arom. H); 6.02–5.92 (*m*, –CH=); 5.29–5.02 (*m*, =CH$_2$); 4.73–4.72 (*m*, CH$_2$); 2.21 (*s*, Me). ^{13}C-NMR ((D$_6$)DMSO): 146.3 (*s*, *C*=C(CN)$_2$); 132.0 (*d*, –CH=); 128.5, 128.3,

128.1 (3*d*, 5 arom. CH); 127.7, 125.0, 123.7 (3*s*, arom. C_q, C(4), C(5)); 120.0 (*s*, C=C(*C*N)$_2$); 117.1 (*t*, = CH_2); 45.8 (*t*, CH_2); 23.2 (*s*, C=*C*(CN)$_2$); 8.7 (*q*, Me). EI-MS: 262 (47, $M^{+\bullet}$), 222 (43), 221 (100), 130 (25), 77 (17).

6. *Isolation of the Complex* **12**. To a soln. of the monohydrate of **1d** (344 mg, 1.0 mmol) in MeOH (4 ml), a soln. of **7** (235 mg, 1.1 mmol) in MeOH (2 ml) was added dropwise, and the mixture was stirred magnetically for 20 min at r.t. The solvent was evaporated *i.v.*, and the oily residue was triturated with *ca*. 3 ml of Et_2O. The separated solid was dissolved in hot MeOH and left to cool. In the refrigerator, crystals of **11d** formed. They were filtered, and the mother liquor was evaporated *i.v.* to dryness. The colorless residue was dissolved in CH_2Cl_2 to give, after cooling in the refrigerator overnight, anal. pure crystals of the 1:1 complex of *hexafluoroacetone hydrate* and *1-benzyl-4,5-diphenyl-1*H-*imidazole 3-oxide* (**12**). Yield: 40 mg (8%). Colorless prisms. M.p. (dec.) 116–117° (CH_2Cl_2). IR: 3450–2360*s* (br., H-bridged

Table. *Crystallographic Data for Compounds* **11d** *and* **12**

		11d	**12**
Crystallized from		MeOH	MeOH
Empirical formula		$C_{25}H_{18}N_4 \cdot MeOH$	$C_{22}H_{18}N_2O \cdot C_3H_2F_6O_2$
Formula weight		406.49	510.43
Crystal color, habit		colorless, prism	colorless, plate
Crystal dimensions [mm]		$0.10 \times 0.27 \times 0.27$	$0.05 \times 0.20 \times 0.37$
Temp. [K]		160(1)	160(1)
Crystal system		triclinic	triclinic
Space group		$P\bar{1}$	$P\bar{1}$
Z		2	2
Reflections for cell determination		5940	5206
2θ Range for cell determination [°]		4–60	4–55
Unit cell parameters	a [Å]	9.5540(5)	10.5912(4)
	b [Å]	10.2090(4)	10.8967(4)
	c [Å]	11.7472(6)	11.6654(5)
	α [°]	70.527(3)	87.757(3)
	β [°]	79.331(2)	79.724(3)
	γ [°]	77.549(3)	62.052(2)
	V [Å^3]	1046.82(9)	1168.67(8)
D_x [g cm^{-3}]		1.289	1.450
μ(MoK_α) [mm^{-1}]		0.0809	0.127
Scan type		ϕ and ω	ϕ and ω
$2\theta_{(max)}$ [°]		60	55
Total reflections measured		25346	26435
Symmetry independent reflections		6094	5333
Reflections with $I > 2\sigma(I)$		3346	3721
Reflections used in refinement		6092	5331
Parameters refined		268	334
Final $R(F)$ [$I > 2\sigma(I)$ reflections]		0.0661	0.0446
$wR(F^2)$ (all data)		0.1974	0.1155
Weighting parameters [a; b][a]		0.1065; 0	0.0520; 0.1644
Goodness-of-fit		0.995	1.057
Secondary extinction coefficient		0.048(9)	0.034(3)
Final Δ_{max}/σ		0.001	0.001
$\Delta\rho$ (max; min) [e Å^{-3}]		0.37; −0.29	0.20; −0.21

[a]) $w^{-1} = \sigma^2(F_o^2) + (aP)^2 + bP$ where $P = (F_o^2 + 2F_c^2)/3$.

OH), 1277*m*, 1213*vs* (CF_3), 1173*s*, 1148*m*, 1093*s*, 957*m*, 721*s*, 698*s*. ^{1}H-NMR (CD_3OD): 8.48 (*s*, CH); 7.52–6.84 (*m*, 15 arom. H); 5.11 (*s*, CH_2). ^{19}F-NMR (CD_3OD): −83.6 (2 CF_3). CI-MS: 328 (26), 327 (100, $[M-C_3H_2F_6O_2+1]^+$). Anal. calc. for $C_{25}H_{20}F_6N_2O_3$ (510.43): C 58.83, H 3.95; found C 58.43, H 3.98.

7. *X-Ray Crystal-Structure Determination of* **11d** *and* **12** (*Table* and *Figs. 1–2*)[3]). All measurements were performed on a *Nonius KappaCCD* diffractometer [36] using graphite-monochromated MoK_α radiation (λ 0.71073 Å) and an *Oxford Cryosystems Cryostream* 700 cooler. The data collection and refinement parameters are given in the *Table*, and views of the molecules are shown in *Figs. 1* and *2*. Data reduction was performed with *HKL Denzo* and *Scalepack* [37]. The intensities were corrected for *Lorentz* and polarization effects but not for absorption. Equivalent reflections were merged. The structures were solved by direct methods using SIR92 [38], which revealed the positions of all non-H-atoms. The asymmetric unit of **11d** contains one molecule of the heterocycle and one highly disordered MeOH molecule. The disorder of the latter could not be modelled adequately, so the SQUEEZE routine [20] of the program PLATON [21] was employed. This procedure, which allows the disordered solvent molecules to be omitted entirely from the subsequent refinement model, gave better refinement results, and there were no significant peaks of residual electron density to be found in the voids of the structure. The procedure leaves one cavity of 111 Å^3 per unit cell. The electron count in the disordered region was calculated to be 26 e per cavity, although this can be an underbound. Allowing for two MeOH molecules per cavity (one per asymmetric unit, which corresponds with the estimate from the original attempt to model the solvent molecule) yields 36 e, and this estimate was used in the subsequent calculation of the empirical formula, formula weight, density, linear absorption coefficient, and $F(000)$. The asymmetric unit of **12** contains two chemically distinct moieties. The non-H-atoms of **11d** and **12** were refined anisotropically. The HN-atom of **11d** and the HO-atoms of **12** were paced in the positions indicated by difference electron density maps, and their positions were allowed to refine together with individual isotropic displacement parameters. All remaining H-atoms were placed in geometrically calculated positions and refined using a riding model where each H-atom was assigned a fixed isotropic displacement parameter with a value equal to 1.2 U_{eq} of its parent C-atom. The refinement of each structure was carried out on F^2 using full-matrix least-squares procedures, which minimized the function $\Sigma w(F_o^2 - F_c^2)^2$. Corrections for secondary extinction were applied. In each case, two reflections, whose intensities were considered to be extreme outliers, were omitted from the final refinement. Neutral atom scattering factors for non-H-atoms were taken from [39a], and the scattering factors for H-atoms were taken from [40]. Anomalous dispersion effects were included in F_c [41]; the values for f' and f'' were those of [39b]. The values of the mass attenuation coefficients are those of [39c]. All calculations were performed using the *SHELXL97* [42] program.

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