# New Studies on [2 + 3] Cycloadditions of Thermally Generated *N*-Isopropyl- and *N*-(4-Methoxyphenyl)-Substituted Azomethine Ylides

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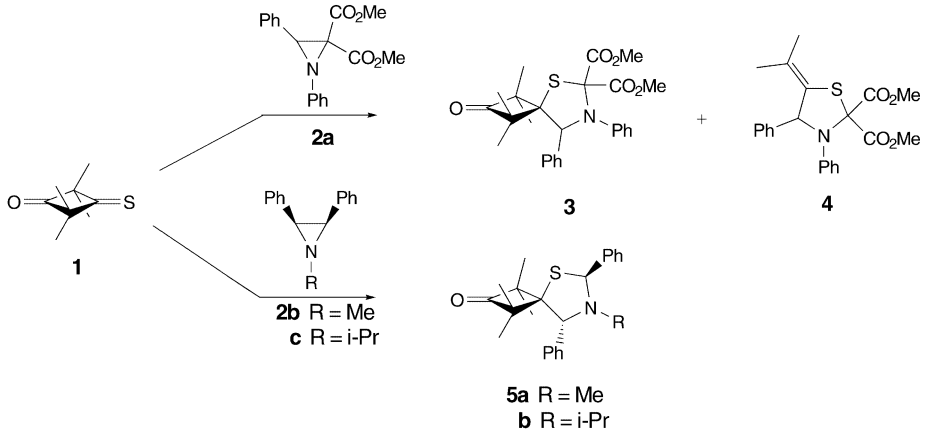
The thermal reaction of 1-substituted 2,3-diphenylaziridines **2** with thiobenzophenone (**6a**) and 9*H*-fluorene-9-thione (**6b**) led to the corresponding 1,3-thiazolidines (*Scheme 2*). Whereas the *cis*-disubstituted aziridines and **6a** yielded only *trans*-2,4,5,5-tetraphenyl-1,3-thiazolidines of type **7**, the analogous reaction with **6b** gave a mixture of *trans*- and *cis*-2,4-diphenyl-1,3-thiazolidines **7** and **8**. During chromatography on $SiO_2$, the *trans*-configured spiro[9*H*-fluorene-9,5′-[1,3]thiazolidines] **7c** and **7d** isomerized to the *cis*-isomers. The substituent at N(1) of the aziridine influences the reaction rate significantly, *i.e.*, the more sterically demanding the substituent the slower the reaction. The reaction of *cis*-2,3-diphenylaziridines **2** with dimethyl azodicarboxylate (**9**) and dimethyl acetylenedicarboxylate (**11**) gave the *trans*-cycloadducts **10** and **12**, respectively (*Schemes 3* and *4*). In the latter case, a partial dehydrogenation led to the corresponding pyrroles. Two stereoisomeric cycloadducts, **15** and **16**, with a *trans*-relationship of the Ph groups were obtained from the reaction with dimethyl fumarate (**14**; *Scheme 5*); with dimethyl maleate (**17**), the expected cycloadduct **18** together with the 2,3-dihydropyrrole **19** was obtained (*Scheme 6*). The structures of the cycloadducts **7b**, **8a**, **15b**, and **16b** were established by X-ray crystallography.

**Introduction.** – Recently, we focused our attention on 1,3-dipolar cycloadditions of thiocarbonyl dipolarophiles with azomethine ylides by different procedures for their generation (*cf.* [1] and refs. cit. therein). One of the most frequently used procedures is the thermal, stereoselective ring opening of *N*-substituted aziridines [2][3]. This method was explored to synthesize 1,3-thiazole derivatives in a regio- and stereoselective manner [4–6]. In some cases, drastic reaction conditions were necessary, which led to the formation of unexpected products. For example, the reaction of 2,2,4,4-tetramethyl-3-thioxocyclobutanone (**1**) with dimethyl 1,3-diphenylaziridine-2,2-dicarboxylate (**2a**) gave, among other products, dimethyl 1,3-thiazolidine-2,2-dicarboxylate **4**, which is formally a cycloadduct of the azomethine ylide with dimethylthioketene (*Scheme 1*) [7]. Furthermore, reactions of **1** with 1-methyl- and 1-isopropyl-2,3-diphenylaziridine **2b** and **2c**, respectively, led to the expected 1,3-thiazolidines **5a** and **5b**, respectively, but the reaction with **2c** was considerably slower and accompanied by significant decomposition (*Scheme 1*). This different reactivity can be explained by

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

[2]) Part of the diploma thesis of *R. S.*, University of Łódź.

*Scheme 1*




the assumption of a severe steric interaction between the i-Pr substituent and a Ph group in the intermediate azomethine ylide.

To gain more insight into the influence of the *N*-substituent of 2,3-diphenylaziridines on the reactivity of the azomethine ylides generated therefrom, we compared the reactions of **2b** and **2c** as well as those of *trans*-1-benzyl-2,3-diphenylaziridine (**2d**) and *cis*-1-(4-methoxyphenyl)-2,3-diphenylaziridine (**2e**). For these studies, aromatic thioketones, dimethyl acetylenedicarboxylates, dimethyl fumarate and maleate, as well as dimethyl azodicarboxylate were selected as dipolarophiles.

**Results and Discussion.** – The thermal reaction of **2b** with thiobenzophenone (**6a**) was reported to occur smoothly (4 h) and gave the expected 1,3-thiazolidine **7a** in high yield [8]. Under analogous conditions, **2c** and **6a** yielded, after 24 h, **7b** as the sole product (49%). The predicted *trans*-relationship of the Ph substituents at C(2) and C(4) was confirmed by X-ray crystallography (*Fig. 1*). Under the same conditions, **2d** and **6a** gave, after 7-h heating, the *cis*-configured cycloadduct **8c** in 44% yield.

To compare the reactivities of the aziridines with a Me and i-Pr group, respectively, at the *N*-atom, a mixture of equimolar amounts of **2b**, **2c**, and **6a** in toluene was heated under reflux for 3 h[3]). The ratio **7a**/**7b** was established by $^1$H-NMR spectroscopy: the *singlets* from H–C(2) and H–C(4) of the two adducts (**7a**: 5.40 and 5.13 ppm; **7b**: 5.78 and 5.68 ppm) showed intensities with a ratio of *ca.* 3:1. Based on kinetic evidence, *Huisgen et al.* concluded that, in the case of *N*-benzyl aziridine **2d** and dimethyl fumarate, the rate of the formation of the cycloadduct depends exclusively on the rate of the ring opening [10a]. In our system, the interception of the azomethine ylides by the 'superdipolarophile' **6a** is assumed to occur very fast, and, therefore, the higher yield of **7a** indicates that **2b** undergoes the electrocyclic ring opening faster than **2c**. The bulkier i-Pr substituent apparently reduces the rate of the conrotatory ring opening.

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[3]) After this time, the blue color of **6a** had disappeared completely.

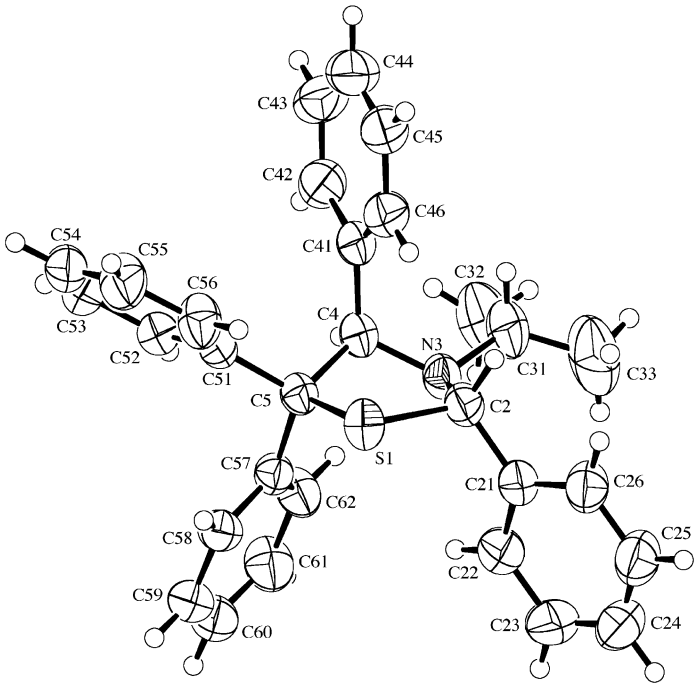


Fig. 1. *ORTEP Plot* [9] *of the molecular structure of one of the two symmetry-independent molecules of* **7b** (40% probability ellipsoids, arbitrary numbering of atoms)

Analogously, the reaction of **2b** with 9*H*-fluorene-9-thione (**6b**) gave **7c** and traces of **8a** ($^1$H-NMR; *Scheme 2*). After chromatography ($SiO_2$), only **8a** was obtained in 35% yield, *i.e.*, an isomerization **7c** → **8a** took place during chromatographic workup. The *cis*-configuration of **8a** has been unambigously confirmed by X-ray crystallography (*Fig. 2*). In the case of **2c** and **6b**, again a mixture of two cycloadducts was formed. The product isolated in 42% yield after chromatographic separation[4]) corresponded to the minor component of the reaction mixture. Based on their spectroscopic data, both products are 3-isopropyl-1,3-thiazolidines, which differ in the relative configuration of the Ph ring at C(2) and C(4). By analogy to the reaction with **2b**, we assign the *trans*-configuration to the major product **7d**, and the *cis*-configuration to **8b**. Thus, the primarily formed *trans*-configured products **7c** and **7d**, *i.e.*, the spirofluorenyl compounds, undergo a smooth isomerization to give the *cis*-isomers **8a** and **8b**, respectively, during chromatographic workup[5]). Attempted separations by fractional crystallization always led to mixtures of the isomers. When a sample of recrystallized material containing **7d** and **8b** (9 : 1 mixture) was dissolved in $CDCl_3$ in the presence of catalytic amounts of $CF_3COOH$, the isomerization to **8b** was complete after 3 d at

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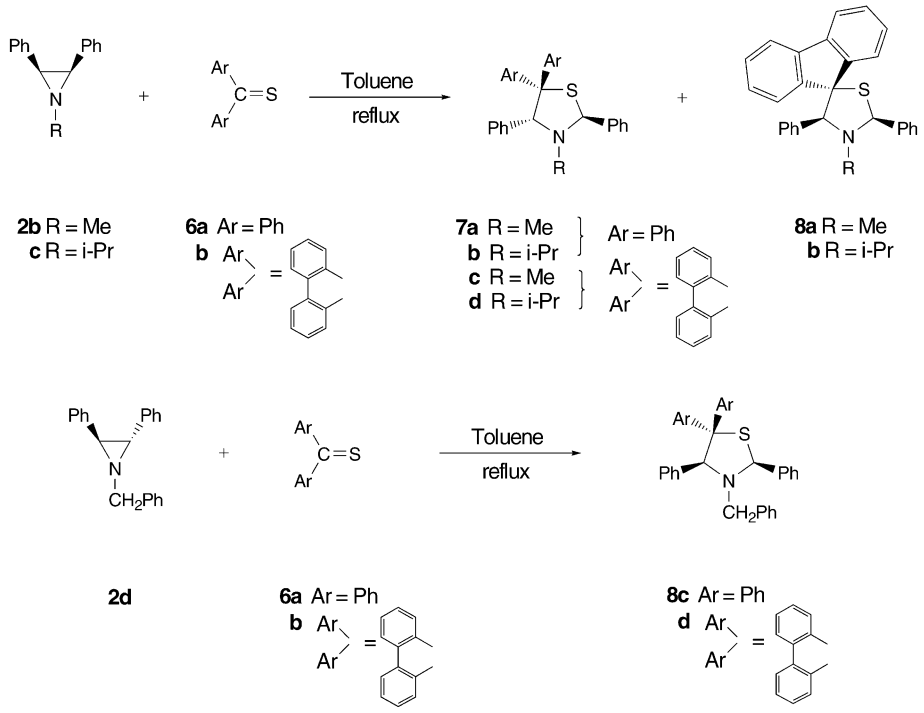
[4]) The ratio **7d**/**8b** of the isolated material depended on how long the mixture was exposed to $SiO_2$. After 12 h, the isomerization was complete.

[5]) It is worth mentioning that an analogous isomerization was not observed in the case of **7b**.

*Scheme 2*



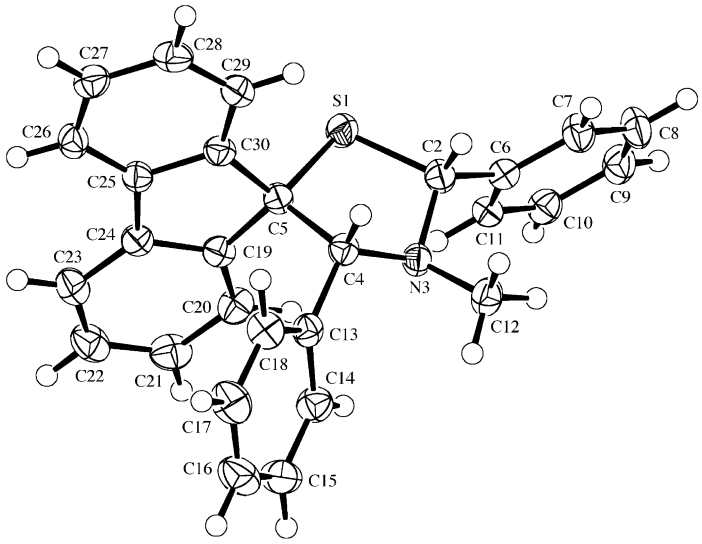



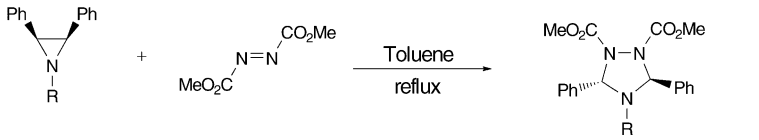

Fig. 2. *ORTEP Plot* [9] *of the molecular structure of one of the two symmetry-independent molecules of* **8a** (50% probability ellipsoids, arbitrary numbering of atoms)

room temperature[6]). This isomerization can be rationalized by a ring-opening/ring-closure process in which a thiocarbonylium ion (*via* cleavage of the C(2)–N(3) bond) or an azomethinium ion (*via* cleavage of the S(1)–C(2) bond) is the intermediate.

The isomerizations of **7c** and **7d** to **8a** and **8b**, respectively, indicate that the *cis*-configured 2,4-diphenyl-1,3-thiazolidines are the thermodynamically more stable stereoisomers. This observation was confirmed in an additional experiment in which *trans*-aziridine **2d** was reacted with **6b**. In this case, only one cycloadduct, **8d** (*Scheme 2*), which was stable during chromatography ($SiO_2$), was found in the mixture. The similarity of its NMR spectra with those of **8a** and **8b** indicated the expected *cis*-configuration.

When a 1:1 mixture of **2c** and dimethyl azodicarboxylate (**9**) was heated in toluene for 15 h[7]), the cycloadduct **10a** (*Scheme 3*) was obtained, which was purified by chromatography on $Al_2O_3$[8]). As an additional precursor of an azomethine ylide, the 1-aryl-substituted aziridine **2e** was reacted with **9** in boiling toluene to give **10b** (*cf.* [12]). In this case, the reaction was complete after only 2 h[9]).

*Scheme 3*




**2c** R = i-Pr
**e** R = 4-MeOC$_6$H$_4$

**9**

**10a** R = i-Pr
**b** R = 4-MeOC$_6$H$_4$

Dimethyl acetylenedicarboxylate (**11**) is frequently used as an electron-deficient dipolarophile (*cf.* [13]). The reaction with **2c** in refluxing toluene was complete after 8 h. By $^1$H-NMR analysis, the products **12a** and **13a** were detected in a ratio of 85:15 (*Scheme 4*). The main differences were the presence of a *singlet* at 5.61 ppm (2 H) and two *doublets* for the i-Pr group in the case of the major product **12a**, whereas **13a** showed only one *doublet* for the i-Pr substituent. Crystallization from MeOH gave **13a**, and subsequent chromatographic separation of the mother liquor led to an additional amount of **13a** and to **12a**. In a second experiment, the mixture was heated for 24 h to yield **13a** exclusively.

The higher reactivity of **2e** was confirmed in the reaction with **11**: here, **2e** was completely consumed after just 1 h. Again, two products were obtained, which were identified as **12b** and **13b**. The smooth conversion of 2,5-dihydro-1*H*-pyrroles into 1*H*-

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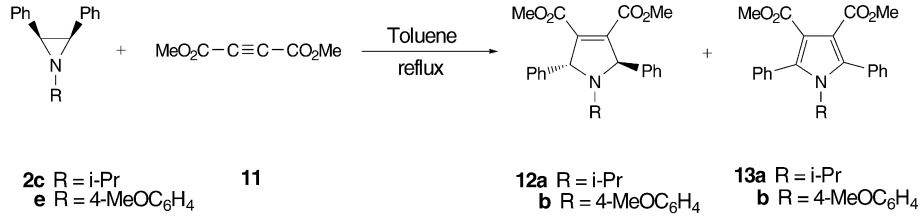
[6]) A similar isomerization of *N*-methyl- and *N*-benzyl-2,4,5-triaryl-1,3-oxazolidines was reported to occur thermally or during chromatography on $SiO_2$ [11b,c].

[7]) No **2c** could be detected after this time.

[8]) First attempts with $SiO_2$ as the adsorbent led to decomposition of **10a**.

[9]) In 1966, *Heine et al.* reported the reaction of 1,2,3-triphenylaziridine with **9** in refluxing toluene (4 h) [3b]. No reaction mechanism was proposed, as, at that time, the electrocyclic ring opening of aziridines to azomethine ylides was not known. Neither the configuration of the starting material nor of the product were given.

*Scheme 4*




**2c** R = i-Pr
**e** R = 4-MeOC$_6$H$_4$

**11**

**12a** R = i-Pr
**b** R = 4-MeOC$_6$H$_4$

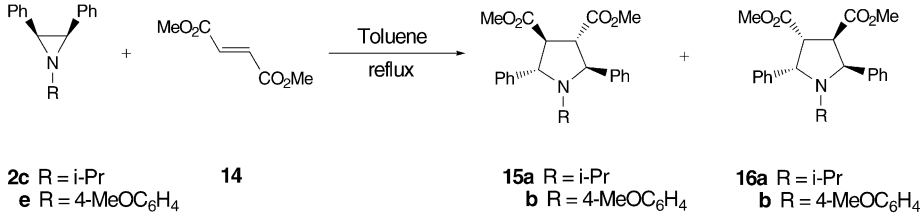
**13a** R = i-Pr
**b** R = 4-MeOC$_6$H$_4$

pyrroles by spontaneous dehydrogenation in the presence of air-$O_2$ (autoxidation) or after addition of an oxidizing agent is well-established [14][15].

Thermal as well as photochemical reactions of 2,3-diarylaziridines with **11** have been reported. Under conditions similar to those described above, *trans*-1-methyl-2,3-diphenylaziridine gave dimethyl *cis*-2,5-dihydro-1-methyl-2,5-diphenyl-1*H*-pyrrole-3,4-dicarboxylate as the sole product [16]. On the other hand, UV irradiation of *trans*-1,2,3-triphenylaziridine in the presence of **11** led to a mixture of the *trans*-disubstituted 2,5-dihydro-1*H*-pyrrole **12** (R = Ph) and the corresponding 1*H*-pyrrole derivative **13** (R = Ph) [15]. In some cases, the formation of 2,3-dihydro-1*H*-pyrroles has been observed. For example, thermolysis of 1-methyl-2-(4-methylphenyl)-3-(2-pyridyl)aziridine and **11** was reported to yield a compound of this type [17]. Furthermore, photolysis of *trans*-1-butyl-2,3-diphenylaziridine and **11** afforded a mixture of all three types of 1*H*-pyrrole derivatives [18]. Apparently, the formation of 2,3-dihydro-1*H*-pyrroles is the result of an isomerization of the initially formed 2,5-dihydro-1*H*-pyrrole[10]).

Both aziridines, **2c** and **2e**, were reacted with dimethyl fumarate (= dimethyl (*E*)-but-2-enedioate; **14**) to yield mixtures of the two diastereoisomeric pyrrolidine-3,4-dicarboxylates **15** and **16** (*Scheme 5*). Whereas the ratio **15a**/**16a** was almost 1:1, it was established as 4:1 in the case of **15b**/**16b**. On the basis of the $^1$H-NMR spectra, we proposed that compounds **15** are the (*r*-2, *t*-3, *c*-4, *t*-5) isomers: H−C(3), H−C(4) absorb as *dd* at *ca.* 4.1 and 3.5 ppm in the cases of **16** and **15**, respectively. The high-field shift in **15a** and **15b** is a result of the shielding effect of the Ph group at C(2) and C(5). The pure isomers of type **15** and **16** were obtained after chromatographic separation, and, in the case of **15b** and **16b**, the predicted structures were established by X-ray

*Scheme 5*




**2c** R = i-Pr
**e** R = 4-MeOC$_6$H$_4$

**14**

**15a** R = i-Pr
**b** R = 4-MeOC$_6$H$_4$

**16a** R = i-Pr
**b** R = 4-MeOC$_6$H$_4$

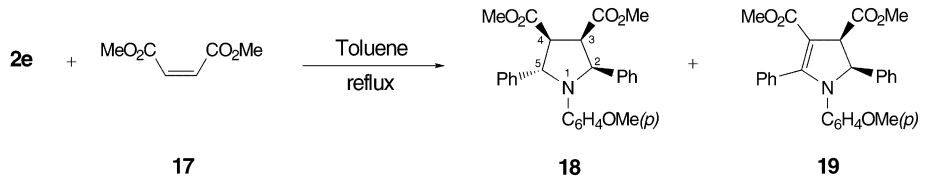
[10]) In analogous reactions with 2-benzoyl- and 2-(methoxycarbonyl)-substituted aziridines, the formation of 2,5-dihydro- and/or 2,3-dihydro-1*H*-pyrroles as well as 1*H*-pyrroles was observed [14][19–22].

crystallography (*Fig. 3*). These results are similar to the ratios reported earlier for the diastereoisomeric pyrrolidinedicarboxylates obtained from the reactions of the corresponding *N*-benzyl- and *N*-Ph-substituted aziridines, respectively, and **14** [10][23].

Dimethyl maleate (**17**) is known to be less reactive than the above dipolarophiles [13]. In a previous study, however, it has been shown that the respective pyrrolidine was formed *via* interception of the azomethine ylide generated either by thermal ring opening of **2b** or by addition of methyl(phenyl)carbene to *N*-benzylidenemethylamine [24]. Unexpectedly, thermolysis of **2c** in the presence of **17** gave none of the expected interception products. After heating for 100 h, analysis of the crude mixture showed the presence of small amounts of **15a** and **16a**, *i.e.*, the products of the reaction with **14** (*Scheme 5*). This result shows that **17** is not reactive enough to trap the intermediate azomethine ylide. Instead, slow isomerization of **17** to **14** takes place.

On the other hand, the reaction of **2e** and **17** in boiling toluene for 24 h led to a mixture of the expected [2+3] cycloadduct **18** and the 2,3-dihydro-1*H*-pyrrole **19**, which is a partially dehydrogenated product of **18**, in a ratio of 5:2 (*Scheme 6*)[11]). The partial dehydrogenation of **18** could, in principle, lead to three different products, one of them being the already described **12b**. The elucidation of the structure of **19** was based on the disappearence of the high-field-shifted *dd* for H–C(4) ($\delta$ 3.40 ppm) and the signal of one of the H-atoms ascribed to H–C(2) and H–C(5) ($\delta$ 5.60/5.84 ppm) in **18**.

*Scheme 6*




**17** **18** **19**

In summary, the present study shows that the *N*-substituent of *cis*-2,3-diphenylaziridines **2** significantly influences their reactivity as precursors of the corresponding azomethine ylides. In all cases, the *N*-isopropyl derivative showed the lowest reactivity, but, in spite of this, [2+3] cycloaddition products with C=S, N=N, and electron deficient C≡C dipolarophiles were obtained. The formation of a cycloadduct was also observed in the case of dimethyl fumarate, whereas no reaction occurred with dimethyl maleate. The influence of the i-Pr substituent compared with that of a Me or 4-$MeOC_6H_4$ group is remarkable. It seems likely that steric as well as electronic effects are responsible for the reduced stability of the ylide and for its slower formation. Furthermore, steric hindrance may be the reason for the more sluggish cycloaddition reaction that generates five-membered heterocycles.

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[11]) In an earlier experiment with *cis*-1,2,3-triphenylaziridine and **17**, *Huisgen et al.* described the cycloadduct analogous to **18**, but no secondary product of type **19** was mentioned [10b].

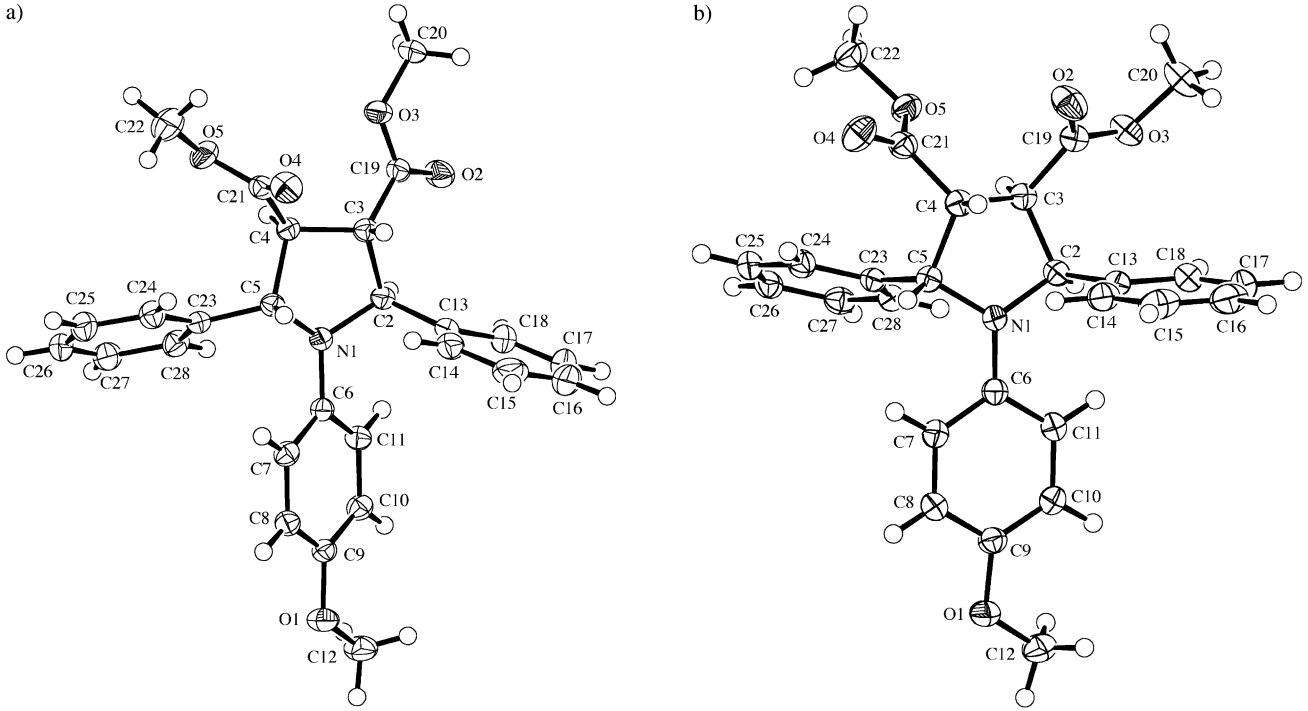


Fig. 3. *ORTEP Plots* [9] *of the molecular structures of* **15b** *and* **16b** (50% probability ellipsoids; arbitrary numbering of atoms)

## Experimental Part

1. *General*. See [25].

2. *Starting Materials.* cis-*1-Methyl-2,3-diphenylaziridine* (**2b**) and cis-*1-isopropyl-2,3-diphenylaziridine* (**2c**) were prepared by *Gabriel*'s method according to [11], trans-*1-benzyl-2,3-diphenylaziridine* (**2d**) and cis-*1-(4-methoxyphenyl)-2,3-diphenylaziridine* (**2e**) were synthesized according to procedures described by *Huisgen et al.* [10][23]. *Thiobenzophenone* (**6a**) was obtained from benzophenone by treatment with *Lawesson*'s reagent [26], and 9H-*fluorene-9-thione* (**6b**) was prepared according to [27] by thionation of 9*H*-fluorenone with a $H_2S$/HCl mixture at 0–5° in EtOH. Other reagents used in the present study were commercially available. Reported yields refer to isolated products.

3. *Thermal Reactions of Aziridines* **2b**–**2d** *with Dipolarophiles.* 3.1. *Reaction of* **2c** *with* **6a**. A soln. of **2c** (261 mg, 1.1 mmol) and freshly purified, blue **6a** (198 mg, 1.0 mmol) dissolved in toluene (4 ml) was heated under reflux for 24 h. After this time, the blue color of **6a** disappeared; the mixture was cooled to r.t., and the solvent was removed *in vacuo*. The thick, oily residue was analyzed by $^1$H-NMR, and only one product with two *s* for CH at 5.68 and 5.78 ppm was detected. Isolation of the product was achieved chromatographically ($SiO_2$; petroleum ether with increasing amounts of $CH_2Cl_2$). The $^1$H-NMR spectrum of the isolated material corresponded to that recorded for the crude mixture.

trans-*3-Isopropyl-2,4,5,5-tetraphenyl-1,3-thiazolidine* (**7b**). Yield: 213 mg (49%). Colorless crystals. M.p. 99–101° (dec.; blue color; MeOH). IR (KBr): 1601*m*, 1492*s*, 1454*s*, 1362*m*, 1239*s*, 1181*s*, 749*s*, 729*s*, 696*vs*. $^1$H-NMR: 0.58, 1.07 (2*d*, $J$ = 6.6, *Me*$_2$CH); 2.99 (*m*, Me$_2$C*H*); 5.68, 5.78 (2*s*, H–C(4), H–C(2)); 6.84–7.67 (*m*, 20 arom. H). $^{13}$C-NMR: 19.3, 21.7 (2*q*, *Me*$_2$CH); 48.8 (*d*, Me$_2$*C*H); 68.9 (*s*, C(5)); 69.9, 73.9 (*2d*, C(4), C(2)); 125.7, 125.9, 126.8, 127.2, 127.4, 127.5, 127.7, 128.0, 128.1, 129.0, 130.1 (11*d*, 20 arom. CH); 140.3, 142.5, 143.4, 150.7 (4*s*, 4 arom. C). CI-MS ($NH_3$): 436 (100, $[M+1]^+$), 230 (7), 208 (7). Anal. calc. for $C_{30}H_{29}NS$ (435.63): C 82.72, H 6.71, N 3.22, S 7.36; found: C 82.74, H 6.65, N 3.26, S 7.46.

3.2. *Reaction of* **2d** *with* **6a**. A soln. of **2d** (314 mg, 1.1 mmol) and **6a** (198 mg, 1.0 mmol) in toluene was heated under reflux for 7 h. The analysis of the crude mixture and isolation of the product were carried out as described in *3.1*.

cis-*3-Benzyl-2,4,5,5-tetraphenyl-1,3-thiazolidine* (**8c**). Yield: 213 mg (44%). Colorless crystals. M.p. 121–123° (MeOH). IR (KBr): 1500*s*, 1460*s*, 1450*s*, 1220*m*, 1150*m* (br.), 1090*m*, 1050*m*, 780*s*, 770*s*, 710*vs*. $^1$H-NMR: 3.70, 3.76 (*AB*, $J$ = 14.0, $CH_2$); 5.17, 5.25 (2*s*, H–C(4), H–C(2)); 6.92–7.74 (*m*, 20 arom. H). $^{13}$C-NMR: 51.8 (*t*, $CH_2$); 68.4 (*s*, C(5)); 69.5, 72.5 (*2d*, C(4), C(2)); 126.2, 126.3, 127.0, 127.2, 127.8, 127.9, 128.1, 128.3, 128.7, 130.0, 130.2, 130.7 (12*d*, 20 arom. CH); 134.9, 138.5, 139.9, 142.7, 147.1 (5*s*, 5 arom. C). EI-MS: 285 (76), 195 (21), 194 (100), 178 (6), 121 (8), 91 (20). Anal. calc. for $C_{34}H_{29}NS$ (483.68): C 84.43, H 6.04, N 2.89, S 6.63; found: C 84.59, H 6.04, N 2.90, S 6.39.

3.3. *Reactions of* **2b**, **2c**, *and* **2d** *with* **6b**. A soln. of 1.1 mmol of the corresponding aziridine **2** in 2 ml of toluene was heated under reflux. To these mixtures, a soln. of **6b** (196 mg, 1 mmol) in toluene (2 ml) was added in three portions in intervals of *ca*. 20 min.

*Reaction with* **2b**. The reaction was complete after 2 h. After careful evaporation of the solvent, the thick oily residue was analyzed by $^1$H-NMR (presence of two *s* for CH at 6.06 and 4.98 ppm, resp.). After chromatographic workup ($SiO_2$; petroleum ether with increasing amounts of $CH_2Cl_2$), a colorless, thick oil was isolated, which subsequently solidified in the refrigerator. Crystallization from MeOH afforded an anal. pure sample of **8a**.

trans-*3′-Methyl-2′,4′-diphenylspiro[9*H*-fluorene-9,5′-[1,3]thiazolidine]* (**7c**, unstable primary cycloadduct). $^1$H-NMR: 2.05 (*s*, MeN); 4.98, 6.06 (2*s*, H–C(4′), H–C(2′)).

cis-*3′-Methyl-2′,4′-diphenylspiro[9*H*-fluorene-9,5′-[1,3]thiazolidine]* (**8a**). Yield: 140 mg (35%). Colorless needles. M.p. 154–156° (MeOH/$CH_2Cl_2$). IR (KBr): 1493*m*, 1448*s*, 1244*m*, 1144*m*, 1024*m*, 959*m*, 745*vs*, 732*vs*, 701*s*. $^1$H-NMR: 2.20 (*s*, MeN); 4.25, 5.18 (2*s*, H–C(4′), H–C(2′)); 6.74–8.21 (*m*, 18 arom. H). $^{13}$C-NMR: 39.2 (*q*, MeN); 66.2 (*s*, C(5′)); 75.3, 84.2 (2*d*, C(4′), C(2′)); 118.9, 119.6, 124.9, 126.8, 127.2, 127.5, 127.6, 127.9, 128.2, 128.3, 128.5, 128.8 (12*d*, 18 arom. CH); 134.9, 139.1, 139.6, 140.8, 146.9, 148.5 (6*s*, 6 arom. C). CI-MS ($NH_3$): 422 (15, $[M+NH_3]^+$), 406 (97, $[M+1]^+$), 284 (41), 152 (100). Anal. calc. for $C_{28}H_{23}NS$ (405.57): C 82.92, H 5.72, N 3.45, S 7.91; found: C 82.95, H 5.87, N 3.36, S 8.08.

*Reaction with* **2c**. The reaction was complete after 13 h. After evaporation of the solvent, the thick oily residue was analyzed by $^1$H-NMR (presence of two sets of *s* at 5.17 and 6.30, and at 4.73 and 5.77 ppm, attributed to H–C(4) and H–C(2) of **7d** and **8b**, resp.; ratio of isomers *ca*. 7:3). After chromatographic separation ($SiO_2$; petroleum ether with increasing amounts of $CH_2Cl_2$), a crystalline fraction identified as a 2:8 mixture of **7d** and **8b** was isolated. Attempted separation by fractional crystallization failed. In a second experiment, the crude

mixture of **7d** and **8b** was put on a $SiO_2$ column, and the separation was carried out only after 12 h. In this case, only isomerized cycloadduct **8b** was isolated and purified by crystallization.

cis-*3′-Isopropyl-2′,4′-diphenylspiro[9*H*-fluorene-9,5′-[1,3]thiazolidine]* (**8b**). Yield: 182 mg (42%). Colorless crystals. M.p. 162–164° (MeOH/$CH_2Cl_2$). IR (KBr): 1448*s*, 1384*w*, 1174*m*, 1155*m*, 748*s*, 731v*s*, 702v*s*. $^1$H-NMR: 0.77, 0.98 (2*d*, $J$ = 7.1, 6.7, $Me_2$CH); 3.19 (*m*, $Me_2CH$); 4.73, 5.77 (2*s*, H–C(4′), H–C(2′)); 6.67–8.19 (*m*, 18 arom. H). $^{13}$C-NMR: 14.8, 21.8 (2*q*, $Me_2$CH); 49.9 (*d*, $Me_2$CH); 65.5 (*s*, C(5′)); 68.2, 81.2 (*2d*, C(4′), C(2′)); 118.8, 119.4, 124.7, 126.5, 126.6, 127.0, 127.3, 127.4, 127.9, 128.0, 128.2, 128.3, 128.6 (13*d*, 18 arom. CH); 136.1, 139.2, 140.7, 141.9, 147.7, 148.8 (6*s*, 6 arom. C). CI-MS ($NH_3$): 434 (100, $[M+1]^+$), 400 (17), 312 (23), 180 (7), 148 (15), 106 (7). Anal. calc. for $C_{30}H_{27}NS$ (433.61): C 83.10, H 6.28, N 3.23, S 7.39; found: C 83.14, H 6.27, N 3.23, S 7.53.

*Reaction with* **2d**. The reaction was complete after 1 h, and the crude mixture was purified by chromatography according to the procedure described for **2b**.

cis-*3′-Benzyl-2′,4′-diphenylspiro[9*H*-fluorene-9,5′-[1,3]thiazolidine]* (**8d**). Yield: 212 mg (44%). Colorless needles. M.p. 161–162° (MeOH). IR (KBr): 1493*m*, 1448*s*, 1119*m* (br.), 1067*m*, 1029*m*, 748*s*, 700*s*. $^1$H-NMR: 3.89 (*s*, $CH_2$); 4.40, 5.45 (2*s*, H–C(4′), H–C(2′)); 6.58–8.20 (*m*, 23 arom. H). $^{13}$C-NMR: 52.0 (*t*, $CH_2$); 65.9 (*s*, C(5′)); 69.6, 79.7 (2*d*, C(4′)), C(2′)); 119.2, 119.8, 125.1, 127.0, 127.2, 127.5, 127.7, 127.9, 128.1, 128.2, 128.4, 128.7, 128.8, 129.2, 129.4, 130.9 (16*d*, 23 arom. CH); 133.7, 134.9, 139.5, 139.8, 141.1, 147.6, 149.1 (7*s*, 7 arom. C). CI-MS ($NH_3$): 483 (43), 482 (100, $[M+1]^+$), 478 (16), 392 (7), 360 (5), 212 (6), 196 (10). Anal. calc. for $C_{34}H_{27}NS$ (481.66): C 84.78, H 5.65, N 2.91, S 6.66; found: C 84.89, H 5.64, N 2.90, S 6.54.

3.4. *Reactions of* **2c** *and* **2e** *with Dimethyl Azodicarboxylate* (**9**). A soln. of **9** (175 mg, 1.2 mmol) and 1 mmol of the corresponding **2** in abs. toluene (2 ml) was heated under reflux.

*Reaction with* **2c**. After 11 h, additional **9** (29 mg, 0.2 mmol) was added to the mixture, and heating was continued for 4 h (15 h totally). After evaporation of the solvent, the oily residue was worked up by chromatography ($Al_2O_3$; petroleum ether with increasing amounts of $CH_2Cl_2$). The main fraction was obtained with 50% of $CH_2Cl_2$, and **10a** was isolated as a thick, colorless oil. Attempts to obtain a crystalline product were not successful.

*Dimethyl* trans-*4-Isopropyl-3,5-diphenyl-1,2,4-triazolidine-1,2-dicarboxylate* (**10a**). Yield: 276 mg (72%). Colorless, thick oil. IR (neat): 1716*s* (br., C=O), 1444*s*, 1335v*s* (br.), 1209*s* (br.), 1124*s*, 1043*m*, 1028*m*, 972*w*, 827*w*, 760v*s*, 710*s*. $^1$H-NMR: 1.06, 1.29 (2*d*, $J$ = 6.3, 6.5, $Me_2$CH); 3.17 (*m*, $Me_2CH$); 3.96 (*s*, 2 MeO); 6.33 (*s*, H–C(3), H–C(5)); 7.53–7.79 (*m*, 10 arom. H). $^{13}$C-NMR: 21.2, 22.9 (2*q*, $Me_2$CH); 47.1 (*d*, $Me_2$CH); 53.3, 53.4 (2*q*, 2 MeO); 78.3, 78.4 (*2d*, C(3), C(5)); 127.3, 128.3, 128.4 (3*d*, 10 arom. CH); 138.0 (*s*, 2 arom. C); 157.4 (*s*, 2 C=O). Anal. calc. for $C_{21}H_{25}N_3O_4$ (383.45): C 65.78, H 6.57, N 10.96; found: C 65.25, H 6.29, N 10.88.

*Reaction with* **2e**. After heating for 2 h, **2d** was completely consumed. The solvent was evaporated, and the solid residue was analyzed by $^1$H-NMR, which showed the presence of **10b** as the sole product (*s* at 6.78 ppm). The crude product was triturated with a small amount of EtOH, and, after filtration, the crystalline product was purified by recrystallization.

*Dimethyl* trans-*4-(Methoxyphenyl)-3,5-diphenyl-1,2,4-triazolidine-1,2-dicarboxylate* (**10b**). Yield: 320 mg (71%). Colorless crystals. M.p. 156–161° (EtOH/$CH_2Cl_2$) ([12]: 149–151°). IR (KBr): 1716v*s* (C=O), 1515*s*, 1444*s*, 1352v*s*, 1295*s*, 1276*s*, 1252v*s*, 1125*s*, 1038*s*, 819*m*, 763*m*, 706*s*. $^1$H-NMR: 3.48 (br. *s*, 2 MeO); 3.63 (*s*, MeO); 6.35, 6.62 (*AA′BB′*, $J$ = 8.5, 4 arom. H); 6.85 (*s*, H–C(3), H–C(5)); 7.28–7.37 (*m*, 10 arom. H). $^{13}$C-NMR: 53.5, 55.4 (2*q*, 2 MeO); 75.2 (*d*, C(3), C(5)); 114.7, 114.9, 126.7, 128.58, 128.62 (5*d*, 14 arom. CH); 135.7, 137.5, 151.9 (3*s*, 4 arom. C); 157.5 (*s*, 2 C=O). CI-MS ($NH_3$): 449 (7), 448 (25, $[M+1]^+$), 254 (10), 238 (13), 237 (100), 212 (23). Anal. calc. for $C_{28}H_{25}N_3O_5$ (447.49): C 67.10, H 5.63, N 9.39; found: C 67.03, H 5.73, N 9.35.

3.5. *Reactions of* **2c** *and* **2e** *with Dimethyl Acetylenedicarboxylate* (**11**). A soln. of **11** (171 mg, 1.2 mmol) and 1.0 mmol of the corresponding **2** in 2 ml of abs. toluene was heated under reflux.

*Reaction with* **2c**. After 8-h heating, the solvent was evaporated, and the crude residue was analyzed by $^1$H-NMR, which revealed the presence of *ca.* 50% of unconverted **2c**. The cycloadduct **12a** and 1*H*-pyrrole **13a** were present in a ratio of *ca.* 85:15 (based on the intensities of the $Me_2$CH *d* between 0.70 and 1.15 ppm). Chromatographic separation (prep. TLC; $SiO_2$; hexane/$CH_2Cl_2$ 1:1) led to **12a** as the less polar fraction and **13a** as the more polar one. The products were purified by crystallization from MeOH.

In a similar experiment, the mixture was heated for 24 h. After typical workup, the $^1$H-NMR spectrum of the crude residue revealed the presence of **13a** as the sole product. The product was triturated with a small amount of MeOH, filtered, and purified by recrystallization from MeOH.

*Dimethyl* trans-*2,5-Dihydro-1-isopropyl-2,5-diphenyl-1*H*-pyrrole-3,4-dicarboxylate* (**12a**). Yield (after 8 h): 133 mg (35%). Colorless crystals. M.p. 100–102° (MeOH). IR (KBr): 1744v*s* (C=O), 1721v*s* (C=O), 1455*m*, 1433*m*, 1317*s*, 1287*m*, 1244*s*, 1198*s*, 1031*s*, 750*m*, 706*s*. $^1$H-NMR: 0.69, 0.82 (2*d*, $Me_2$CH); 2.87 (*m*, $Me_2CH$); 3.56

(*s*, 2 MeO); 5.61 (*s*, H–C(2), H–C(5)); 7.23–7.42 (*m*, 10 arom. H). $^{13}$C-NMR: 21.5, 21.7 (2*q*, *Me*$_2$CH); 47.1 (*d*, Me$_2$*C*H); 51.8 (*q*, 2 MeO); 71.7 (*d*, C(2), C(5)); 127.7, 128.1, 128.2 (3*d*, 10 arom. CH); 139.6 (*s*, 2 arom. C); 140.8 (*s*, C=C); 163.7 (*s*, 2 C=O). ESI-MS (MeOH): 380 (100, $[M+1]^+$). Anal. calc. for $C_{23}H_{25}NO_4$ (379.45): C 72.80, H 6.65, N 3.69; found: C 72.61, H 6.79, N 3.57.

*Dimethyl 1-Isopropyl-2,5-diphenyl-1*H*-pyrrole-3,4-dicarboxylate* (**13a**). Yield (after 24 h): 318 mg (84%). Colorless crystals. M.p. 174–176° (MeOH). IR (KBr): 1716v*s* (C=O), 1482*s*, 1443*s*, 1341*m*, 1253*s*, 1199v*s*, 1169v*s*, 1061*m*, 766*m*, 703*m*. $^1$H-NMR: 1.11 (*d*, *J* = 7.1, *Me*$_2$CH); 3.59 (*s*, 2 MeO); 4.24 (*m*, Me$_2$C*H*); 7.42 (br. *s*, 10 arom. CH). $^{13}$C-NMR: 23.2 (*q*, *Me*$_2$CH); 50.0 (*d*, Me$_2$*C*H); 51.3 (*q*, 2 MeO); 127.8, 128.6, 131.2 (3*d*, 10 arom. CH); 114.7, 131.8, 136.2 (3*s*, 6 arom. C); 165.3 (*s*, 2 C=O). EI-MS: 377 (100, $M^{+\bullet}$), 346 (17), 335 (67), 304 (72), 303 (49), 272 (19).

*Reaction with* **2e**. The reaction was complete after 1 h. After evaporation of the solvent, the $^1$H-NMR spectrum of the crude residue established the ratio **12b**/**13b** as *ca.* 2:1 (based on the intensities of the of MeO *s* at 3.62 and 3.71 ppm for **12b** and **13b**, resp.). The solvent was evaporated, and the semi-solid residue was dissolved in hot acetone. After cooling to r.t., the material crystallized was filtered and identified as **12b**. After one night in the refrigerator, the mother liquor yielded colorless crystals of **13b**. Anal. pure samples were obtained after recrystallization.

*Dimethyl* trans-*2,5-Dihydro-1-(4-methoxyphenyl)-2,5-diphenyl-1*H*-pyrrole-3,4-dicarboxylate* (**12b**). Yield: 186 mg (42%). Yellow crystals. M.p. 216–219° (acetone). IR (KBr): 1736*s* (C=O), 1720*s* (C=O), 1512*s*, 1454*m*, 1436*m*, 1343*m* (br.), 1253*s* (br.), 1102*m*, 1030*m*, 815*s*, 759*m*, 703*m*. $^1$H-NMR: 3.56 (*s*, MeO); 3.62 (*s*, 2 MeO); 6.22 (*s*, H–C(2), H–C(5)); 6.37, 6.51 (*AA′BB′*, *J* = 8.8, 4 arom. CH); 7.20–7.34 (*m*, 10 arom. CH). $^{13}$C-NMR: 52.0 (*q*, 2 MeO); 55.2 (*q*, MeO); 71.1 (*d*, C(2), C(5)); 114.1, 115.3, 127.3, 128.0, 128.6 (5*d*, 14 arom. CH); 136.7, 138.0, 138.9 (3*s*, 3 arom. C); 151.2 (*s*, C=C, 1 arom. C); 163.1 (*s*, 2 C=O). CI-MS ($NH_3$): 444 (100, $[M+1]^+$), 306 (7), 225 (10). Anal. calc. for $C_{27}H_{25}NO_5$ (443.50): C 73.12, H 5.68, N 3.16; found: C 73.04, H 5.71, N 3.14.

*Dimethyl 1-(4-Methoxyphenyl)-2,5-diphenyl-1*H*-pyrrole-3,4-dicarboxylate* (**13b**). Yield: 102 mg (23%). Colorless crystals. M.p. 196–198° (acetone; [28]: 210–211°). IR (KBr): 1731v*s* (C=O), 1712v*s* (C=O), 1515*s*, 1483*s*, 1445*s*, 1254*s*, 1212*s*, 1182*s*, 1102*m*, 1061*m*, 763*m*, 701*m*. $^1$H-NMR: 3.66 (*s*, MeO); 3.71 (*s*, 2 MeO); 6.58, 6.74 (*AA′BB′*, *J* = 8.9, 4 arom. CH); 7.17–7.25 (*m*, 10 arom. CH). $^{13}$C-NMR: 51.6 (*q*, 2 MeO); 55.1 (*q*, MeO); 113.6, 127.5, 127.9, 129.7, 130.7 (5*d*, 14 arom. CH); 114.6, 130.4, 136.8, 158.6 (4*s*, 8 arom. C); 165.5 (*s*, 2 C=O). CI-MS: 442 (100, $[M+1]^+$), 427 (7), 306 (13). Anal. calc. for $C_{27}H_{23}NO_5$ (441.48): C 73.46, H 5.25, N 3.17; found: C 73.53, H 5.25, N 3.14.

3.6. *Reactions of* **2c** *and* **2e** *with Dimethyl Fumarate* (**14**). A soln. of **14** (173 mg, 1.2 mmol) and 1.0 mmol of the corresponding **2** in 2 ml of abs. toluene was heated under reflux. The progress of the reaction was followed by TLC.

*Reaction with* **2c**. After heating for 18 h, the solvent was evaporated, and the crude residue was analyzed by $^1$H-NMR. Based on the intensities of the Me$_2$C*H m* at 2.70 and 3.02 ppm, the ratio **15a**/**16a** was established as *ca.* 1:1. After evaporation of $CDCl_3$, the residue was dissolved in hot MeOH, cooled to r.t., and kept overnight in the refrigerator. Colorless crystals of **16a** were filtered, and the mother liquor was evaporated. The semi-solid residue was separated by prep. TLC ($SiO_2$; hexane/$CH_2Cl_2$). The less polar main fraction was isolated and identified as **15a**, and some additional **16a** was obtained as the more polar fraction.

*Dimethyl* trans,trans,trans-*1-Isopropyl-2,5-diphenylpyrrolidine-3,4-dicarboxylate* (**15a**). Yield: 88 mg (23%). Colorless crystals. M.p. 42–45° (hexane). IR (KBr): 1732v*s* (C=O), 1456*m*, 1436*m*, 1263*m*, 1206v*s*, 1174*s*, 1005*w*, 762*m*, 704*s*. $^1$H-NMR: 0.27, 0.83 (2*d*, *J* = 6.7, 6.9, *Me*$_2$CH); 2.70 (*m*, Me$_2$C*H*); 3.42 (*m*, 2 H); 3.57 (*s*, 2 MeO); 4.72 (*m*, 2 H); 7.13–7.34 (*m*, 10 arom. CH). $^{13}$C-NMR: 18.8, 20.6 (2*q*, *Me*$_2$CH); 46.6 (*d*, Me$_2$*C*H); 52.0, 52.1 (2*q*, 2 MeO); 55.0, 67.1 (2*d*, C(2), C(3), C(4), C(5)); 127.4, 128.2, 128.3 (3*d*, 5 arom. CH); 143.8 (*s*, 2 arom. C); 173.6 (*s*, 2 C=O). CI-MS ($NH_3$): 382 (100, $[M+1]^+$). Anal. calc. for $C_{23}H_{27}NO_4$ (381.47): C 72.42, H 7.13, N 3.67; found: C 72.04, H 6.91, N 3.50.

*Dimethyl* cis,trans,cis-*1-Isopropyl-2,5-diphenylpyrrolidine-3,4-dicarboxylate* (**16a**). Yield: 88 mg (23%). Colorless crystals. M.p. 111–113° (MeOH). IR (KBr): 1744v*s* (C=O), 1732v*s* (C=O), 1454*m*, 1440*m*, 1209v*s*, 1172*s*, 1006*m*, 703*s*. $^1$H-NMR: 0.80, 0.82 (2*d*, *J* = 6.7, 7.0, *Me*$_2$CH); 3.02 (*m*, Me$_2$C*H*); 3.26 (*s*, 2 MeO); 4.10 (*m*, 2 H); 5.01 (*m*, 2 H); 7.20–7.30 (*m*, 10 arom H). $^{13}$C-NMR: 21.7, 22.8 (2*q*, *Me*$_2$CH); 48.3 (*d*, Me$_2$*C*H); 49.4 (*d*, C(3), C(4)); 51.2 (*q*, 2 MeO); 65.8 (*d*, C(2), C(5)); 127.3, 127.8, 127.9 (3*d*, 10 arom. CH); 141.8 (*s*, 2 arom. C); 170.7 (*s*, 2 C=O). EI-MS: 381 (<1, $M^{+\bullet}$), 366 (100, $[M-Me]^+$), 338 (44), 194 (41), 150 (24). Anal. calc. for $C_{23}H_{27}NO_4$ (381.47): C 72.42, H 7.13, N 3.67; found: C 72.34, H 7.20, N 3.54.

*Reaction with* **2e**. The reaction was complete after 12 h. The solvent was evaporated, and the crude residue was analyzed by $^1$H-NMR. Based on the intensities of signals at 5.66 (*m*, H–C(2), H–C(5) in **15b**) and

5.44 ppm (*m*, H–C(2), H–C(5) in **16b**), the ratio **15b**/**16b** was established as *ca.* 1:2. Attempted separation of the diastereoisomers by fractional crystallization failed. Chromatography (prep. TLC; $SiO_2$; hexane/$CH_2Cl_2$ 1:4) led to **15b** as the less polar fraction and **16b** as the more polar one. Recrystallization gave anal. pure samples.

*Dimethyl* trans,trans,trans-*1-(4-Methoxyphenyl)-2,5-diphenylpyrrolidine-3,4-dicarboxylate* (**15b**). Yield: 334 mg (75%). M.p. 132–134° (MeOH/$CH_2Cl_2$). IR (KBr): 1732*s* (C=O), 1513*s*, 1455*m*, 1438*m*, 1244v*s*, 1038*m*, 816*m*, 763*m*, 703*m*. $^1$H-NMR: 3.54 (*s*, 2 MeO); 3.54–3.59 (*m*, H–C(3), H–C(4)); 3.59 (*s*, MeO); 5.65–5.67 (*m*, H–C(2), H–C(5)); 6.32, 6.52 (*AA′BB′*, *J* = 9.1, 4 arom. H); 7.15–7.27 (*m*, 10 arom. H). $^{13}$C-NMR: 52.2 (*q*, 2 MeO); 55.2 (*q*, MeO); 55.3 (*d*, C(3), C(4)); 66.0 (*d*, C(2), C(5)); 113.9, 117.0, 126.6, 127.1, 128.4 (5*d*, 14 arom. CH); 138.2, 141.7, 151.3 (3*s*, 4 arom. C); 172.0 (*s*, 2 C=O). CI-MS ($NH_3$): 447 (30), 446 (100, $[M+1]^+$), 236 (24), 222 (47). Anal. calc. for $C_{27}H_{27}NO_5$ (445.51): C 72.79, H 6.11, N 3.14; found: C 72.73, H 6.05, N 3.06.

*Dimethyl* cis,trans,cis-*1-(4-Methoxyphenyl)-2,5-diphenylpyrrolidine-3,4-dicarboxylate* (**16b**). Yield: 85 mg (19%). Colorless crystals. M.p. 263–265° (MeOH/$CH_2Cl_2$). IR (KBr): 1733v*s* (C=O), 1511v*s*, 1454*m*, 1437*m*, 1297*m*, 1259*s*, 1239*s*, 1219*s*, 1177v*s*, 1041*m*, 814*m*, 755*m*, 704*m*. $^1$H-NMR: 3.34 (*s*, 2 MeO); 3.52 (*s*, MeO); 4.07 (*m*, H–C(3), H–C(4)); 5.44 (*m*, H–C(2), H–C(5)); 6.20, 6.48 (*AA′BB′*, *J* = 8.5, 4 arom. H); 7.11–7.25 (*m*, 10 arom. H). $^{13}$C-NMR: 48.7 (*d*, C(3), C(4)); 51.6 (*q*, 2 MeO); 55.3 (*q*, MeO); 63.9 (*d*, C(2), C(5)); 114.4, 126.9, 127.8, 128.4 (4*d*, 14 arom. CH); 137.8, 138.9, 151.0 (3*s*, 4 arom. C); 169.7 (*s*, 2 C=O). Anal. calc. for $C_{27}H_{27}NO_5$ (445.51): C 72.79, H 6.11, N 3.14; found: C 72.73, H 6.05, N 3.06.

3.7. *Reaction of* **2d** *with Dimethyl Maleate* (**17**). A soln. of **17** (173 mg, 1.2 mmol) and **2d** (285 mg, 1.0 mmol) in abs. toluene (2 ml) was heated under reflux. After 24 h, no **2d** was detected (TLC). The solvent was evaporated, and the crude residue was analyzed by $^1$H-NMR showing the presence of **18**/**19** in a ratio of 2:1. After evaporation of $CDCl_3$, the solid residue was dissolved in hot EtOH. After cooling to r.t., the colorless precipitate was filtered and identified as **18**. The mother liquor was kept in the refrigerator, and, the next day, crystalline **19** was filtered. Recrystallization of the crude products led to anal. pure compounds.

*Dimethyl* cis,cis,trans-*1-(4-Methoxyphenyl)-2,5-diphenylpyrrolidine-3,4-dicarboxylate* (**18**). Yield: 192 mg (43%). Colorless crystals. M.p. 197–199° (EtOH/$CH_2Cl_2$). IR (KBr): 1744*s* (C=O), 1514v*s*, 1454*m*, 1438*m*, 1243*s* (br.), 1217*s* (br.), 1178*m*, 1039*m*, 815*w*, 700*m*. $^1$H-NMR: 3.18, 3.54, 3.62 (3*s*, 3 MeO); 3.40, 3.87 (2*dd*, H–C(3), H–C(4)); 5.60, 5.84 (*AB*, *J* = 7.2, H–C(2), H–C(5)); 6.27, 6.41 (*AA′BB′*, *J* = 9.0, 4 arom. H); 7.10–7.41 (*m*, 10 arom. H). $^{13}$C-NMR: 51.3, 51.9, 52.8 (3*q*, 3 MeO); 55.1 (*d*, C(3), C(4)); 65.8, 66.7 (2*d*, C(2), C(5)); 113.3, 118.7, 126.9, 127.4, 127.5, 127.8, 127.9, 128.2 (8*d*, 14 arom. CH); 137.9, 138.2, 143.3, 151.2 (4*s*, 4 arom. C); 171.0 (*s*, 2 C=O). CI-MS ($NH_3$): 447 (28), 446 (100, $[M+1]^+$), 444 (5). Anal. calc. for $C_{27}H_{27}NO_5$ (445.51): C 72.79, H 6.11, N 3.14; found: C 72.61, H 6.15, N 3.12.

*Dimethyl* trans-*4,5-Dihydro-1-(4-methoxyphenyl)-2,5-diphenyl-1*H*-pyrrole-3,4-dicarboxylate* (**19**). Yield: 75 mg (17%). Colorless crystals. M.p. 152–154° (EtOH/$CH_2Cl_2$). IR (KBr): 2949*m*, 1736v*s*, 1674*s*, 1611*s*, 1593*s*, 1573*s*, 1509*s*, 1437*s*, 1363*s* (br.), 1210v*s* (br.), 1114*s*, 1055*s*, 1030*s*, 840*s*, 765*s*, 696*s*. $^1$H-NMR: 3.53, 3.62, 3.79 (3*s*, 3 MeO); 3.94, 4.96 (*AB*, *J* = 5.5, H–C(4), H–C(5)); 6.51, 6.62 (*AA′BB′*, *J* = 9.0, 4 arom. H); 7.22–7.48 (*m*, 10 arom. H). $^{13}$C-NMR: 50.5, 52.3, 55.1 (3*q*, 3 MeO); 56.5, 73.0 (2*d*, C(4), C(5)); 99.1 (*s*, C(3)); 113.8, 126.3, 126.7, 127.5, 128.0, 128.9, 129.2, 130.0 (8*d*, 14 arom. CH); 161.0 (*s*, C(2)); 131.0, 135.5, 142.0, 156.9 (4*s*, 4 arom. C); 165.5, 174.2 (2*s*, 2 C=O). CI-MS ($NH_3$): 444 (100, $[M+1]^+$). Anal. calc. for $C_{27}H_{25}NO_5$ (443.50): C 73.12, H 5.68, N 3.16; found: C 73.05, H 5.69, N 3.15.

4. *Crystal-Structure Determination of* **7b**, **8a**, **15b**, *and* **16b**[12]). All measurements for **7b** were made on a *KM-4 Kuma* diffractometer [29] with graphite monochromatized Cu$K_\alpha$ radiation ($\lambda$ 1.54178 Å). For the other compounds, the measurements were conducted on a *Nonius KappaCCD* area-detector diffractometer [30] with graphite-monochromated Mo$K_\alpha$ radiation ($\lambda$ 0.71073 Å) and an *Oxford Cryosystems Cryostream 700* cooler. The data collection and refinement parameters are given in the *Table*, views of the molecules are shown in *Figs. 1–3*. Data reduction for **7b** was performed with *Dataproc* [31], while *HKL Denzo* and *Scalepack* [32] was used for **8a**, **15b**, and **16b**. The intensities were corrected for *Lorentz* and polarization effects. Anal. [33] and empirical (multi-scan method [34]) absorption corrections were applied for **7b** and **8a**, resp. Each structure was solved by direct methods [35][36], which revealed the positions of all non-H-atoms. The non-H-atoms were

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[12]) CCDC-198065 and 208506-208508 contain the supplementary crystallographic data for this paper. These data can be obtained, free of charge, *via* www.ccdc.cam.ac.uk/conts/retrieving.html (or from the *Cambridge Crystallographic Data Centre*, 12 Union Road, Cambridge CB2 1EZ, U.K.; fax: +44 1223 336033; e-mail: deposit@ccdc.cam.ac.uk).

Table. *Crystallographic Data for Compounds* **7b**, **8a**, **15b**, *and* **16b**

| | **7b** | **8a** | **15b** | **16b** |
|---|---|---|---|---|
| Crystallized from | EtOH | MeOH | MeOH/$CH_2Cl_2$ | MeOH/$CH_2Cl_2$ |
| Empirical formula | $C_{30}H_{29}NS$ | $C_{28}H_{23}NS$ | $C_{27}H_{27}NO_5$ | $C_{27}H_{27}NO_5$ |
| Formula weight | 435.60 | 405.56 | 445.51 | 445.51 |
| Crystal color, habit | colorless, prism | colorless, plate | colorless, prism | colorless, tablet |
| Crystal dimensions [mm] | 0.20 × 0.30 × 0.50 | 0.07 × 0.30 × 0.30 | 0.15 × 0.20 × 0.27 | 0.12 × 0.15 × 0.18 |
| Temp. [K] | 293(1) | 160(1) | 160(1) | 160(1) |
| Crystal system | triclinic | orthorhombic | monoclinic | monoclinic |
| Space group | $P\bar{1}$ | *Pbca* | *Cc* | $P2_1/c$ |
| $Z$ | 4 | 16 | 4 | 4 |
| Reflections for cell determination | 54 | 64406 | 3469 | 5290 |
| $2\theta$ Range for cell determination [°] | 10–22 | 4–55 | 4–60 | 4–55 |
| Unit cell parameters $a$ [Å] | 11.768(2) | 12.9886(1) | 12.4880(2) | 11.0645(2) |
| $b$ [Å] | 15.276(3) | 22.8639(2) | 14.7967(3) | 20.1040(4) |
| $c$ [Å] | 15.660(3) | 28.9652(3) | 13.8734(3) | 10.7831(2) |
| $\alpha$ [°] | 73.90(2) | 90 | 90 | 90 |
| $\beta$ [°] | 71.04(2) | 90 | 116.6317(8) | 110.4783(8) |
| $\gamma$ [°] | 71.87(2) | 90 | 90 | 90 |
| $V$ [Å$^3$] | 2481.1(8) | 8601.8(1) | 2291.57(8) | 2247.02(7) |
| $D_x$ [g cm$^{-3}$] | 1.166 | 1.253 | 1.291 | 1.317 |
| Linear absorption coefficient [mm$^{-1}$] | 1.27 | 0.165 | 0.0888 | 0.0906 |
| Transmission factors [min; max] | 0.592; 0.802 | 0.893; 0.992 | – | – |
| Scan type | $\omega$ | $\phi$ and $\omega$ | $\phi$ and $\omega$ | $\omega$ |
| $2\theta_{(max)}$ [°] | 135 | 55 | 60 | 55 |
| Total reflections measured | 8624 | 89971 | 27716 | 54079 |
| Symmetry-independent reflections | 8293 | 9845 | 3359 | 5131 |
| Reflections with $I > 2\sigma(I)$ | 5705 | 6209 | 2828 | 3831 |
| Reflections used in refinement | 8293 | 9844 | 3358 | 5129 |
| Parameters refined; restraints | 589 | 544 | 302; 2 | 302 |
| Final $R(F)$ ($I > 2\sigma(I)$ reflections) | 0.0546 | 0.0468 | 0.0415 | 0.0438 |
| $wR(F^2)$ (all data) | 0.1887 | 0.1249 | 0.0995 | 0.1154 |
| Weighting parameters [$a$; $b$][a]) | 0.1264; 0.1241 | 0.0625; 0.4740 | 0.0053; 0.1625 | 0.0574; 0.4651 |
| Goodness-of-fit | 1.112 | 1.016 | 1.036 | 1.045 |
| Secondary extinction coefficient | | 0.0011(2) | 0.012(2) | 0.012(2) |
| Final $\Delta_{max}/\sigma$ | 0.003 | 0.001 | 0.001 | 0.001 |
| $\Delta\rho$ (max; min) [e Å$^{-3}$] | 0.88; −0.35 | 0.27; −0.43 | 0.24; −0.19 | 0.20; −0.26 |

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

refined anisotropically. All of the H-atoms were placed in geometrically calculated positions and refined with a riding model where each H-atom was assigned a fixed isotropic displacement parameter with a value equal to $1.2U_{eq}$ of its parent C-atom ($1.5U_{eq}$ for Me groups). In both **7b** and **8a**, there are two symmetry-independent molecules in the asymmetric unit. The atomic coordinates of the two molecules were tested carefully for a relationship from a higher symmetry space group with the program PLATON [37], but none could be found. One Me C-atom in molecule B of **7b**, C(33B), is disordered. Two positions were defined for this atom and the site occupation factor of the major component refined to 0.535(14). Refinement of each structure was carried out on $F^2$ by full-matrix least-squares procedures, which minimized the function $\sum w(F_o^2 - F_c^2)^2$. For **8a**, **15b**, and **16b**, corrections for secondary extinction were applied, and one, one, and two reflections, resp., whose intensities were considered to be extreme outliers, were omitted from the final refinements.

Neutral-atom-scattering factors for the non-H-atoms were taken from [38a], and the scattering factors for H-atoms were taken from [39]. Anomalous dispersion effects were included in $F_c$ [40]; the values for $f'$ and $f''$

were those of [38b]. The values of the mass-attenuation coefficients are those of [38c]. All calculations were performed using SHELXL97 [41].

## REFERENCES


[1] A. Gebert, A. Linden, G. Mloston, H. Heimgartner, *Pol. J. Chem.* **2003**, *77*, 157.
[2] a) R. Huisgen, W. Scheer, G. Szeimies, H. Huber, *Tetrahedron Lett.* **1966**, 377; b) R. Huisgen, W. Scheer, H. Huber, *J. Am. Chem. Soc.* **1967**, *89*, 1753; c) R. Huisgen, W. Scheer, H. Mäder, *Angew. Chem., Int. Ed.* **1969**, *8*, 602; d) H. Hermann, R. Huisgen, H. Mäder, *J. Am. Chem. Soc.* **1971**, *93*, 1779.
[3] a) J. W. Lown, in '1,3-Dipolar Cycloaddition Chemistry', Ed. A. Padwa, Wiley-Interscience, New York, 1984, Vol. 1, p. 653; b) H. W. Heine, R. Peavy, A. J. Durbetaki, *J. Org. Chem.* **1966**, *31*, 3924; c) P. La Porta, L. Capuzzi, F. Bettarini, *Synthesis*, **1994**, 287; d) I. Coldham, A. J. Collis, R. J. Mould, D. E. Robinson, *Synthesis* **1995**, 1147; e) K. Matsumoto, R. Ohta, T. Uchida, H. Nishioka, M. Yoshida, A. Kakehi, *J. Heterocycl. Chem.* **1995**, *32*, 367; f) G. Gonzales, M. V. Martin, M. C. Paredes, *Heterocycles* **2000**, *52*, 237.
[4] a) G. Mloston, A. Linden, H. Heimgartner, *Pol. J. Chem.* **1997**, *71*, 32; b) G. Mloston, A. Linden, H. Heimgartner, *Helv. Chim. Acta* **1998**, *81*, 558.
[5] G. Mloston, K. Urbaniak, H. Heimgartner, *Helv. Chim. Acta* **2002**, *85*, 2056.
[6] A. Gebert, A. Linden, G. Mloston, H. Heimgartner, *Heterocycles* **2002**, *56*, 393.
[7] G. Mloston, K. Urbaniak, A. Linden, H. Heimgartner, *Helv. Chim. Acta* **2002**, *85*, 2644.
[8] G. Mloston, Z. Skrzypek, *Bull. Soc. Chim. Belg.* **1990**, *99*, 167.
[9] C. K. Johnson, 'ORTEP II'. Report ORNL-5138, Oak Ridge National Laboratories, Oak Ridge, Tennessee, 1976.
[10] a) R. Huisgen, C. H. Ross, K. Matsumoto, *Heterocycles* **1981**, *15*, 1131; b) J. H. Hall, R. Huisgen, *J. Chem. Soc., Chem. Commun.* **1971**, 1187.
[11] a) R. Bartnik, G. Mloston, S. Lesniak, *Pol. J. Chem.* **1979**, *53*, 537; b) R. Bartnik, G. Mloston, *Tetrahedron* **1984**, *40*, 2569; c) C. Wittland, M. Arend, N. Risch, *Synthesis* **1996**, 367.
[12] E. Brunn, R. Huisgen, *Tetrahedron Lett.* **1971**, 473.
[13] R. Huisgen, X. Li, H. Giera, E. Langhals, *Helv. Chim. Acta* **2001**, *84*, 981.
[14] D. Ramaiah, M. Muneer, K. R. Gopidas, P. K. Das, N. P. Rath, M. V. George, *J. Org. Chem*. **1996**, *61*, 4240.
[15] O. Tsuge, K. Oe, N. Kawaguchi, *Chem. Lett*. **1981**, 1585.
[16] W. K. Anderson, A. S. Milowsky, *J. Med. Chem*. **1986**, *29*, 2241.
[17] O. Tsuge, K. Sone, S. Urano, K. Matsuda, *J. Org. Chem.* **1982**, *47*, 5171.
[18] C. Gaebert, J. Mattay, *Tetrahedron* **1997**, *53*, 14297.
[19] J. W. Lown, K. Matsumoto, *Can. J. Chem*. **1970**, *48*, 2215.
[20] A. Derdour, F. Texier, *Can J. Chem*. **1985**, *63*, 2245.
[21] E. Vedejs, J. W. Grissom, *J. Org. Chem*. **1988**, *53*, 1882.
[22] A. Boruah, B. Baruah, D. Prajapati, J. S. Sandhu, A. C. Ghosh, *Tetrahedron Lett*. **1996**, *37*, 4203.
[23] J. H. Hall, R. Huisgen, C. H. Ross, W. Scheer, *J. Chem. Soc., Chem. Commun.* **1971**, 1188; see also: R. Bartnik, G. Mloston, *Synthesis* **1983**, 924.
[24] R. Bartnik, in 'Nitrogen, Oxygen and Sulfur Ylide Chemistry', Ed. J. S. Clark, Oxford University Press, Oxford, 2002, pp. 188–190.
[25] G. Mloston, J. Romanski, H. Heimgartner, *Pol. J. Chem.* **2001**, *75*, 975.
[26] B. S. Pedersen, S. Scheibye, N. H. Nilsson, S.-O. Lawesson, *Bull. Soc. Chim. Belg.* **1978**, *87*, 223.
[27] E. Campaigne, W. B. Reid, *J. Am. Chem. Soc.* **1946**, *68*, 769.
[28] W. E. McEwen, A. S. Grossi, R. J. MacDonald, A. P. Stamegna, *J. Org. Chem.* **1980**, *45*, 1301.
[29] Kuma, Data Collection Program, Version v.10.2.1. Kuma Diffraction, Wroclaw, Poland, 1998.
[30] R. Hooft, KappaCCD Collect Software, Nonius BV, Delft, The Netherlands, 1999.
[31] Kuma, Dataproc Kuma Diffraction. Kuma Diffraction, Wroclaw, Poland, 1996.
[32] Z. Otwinowski, W. Minor, in 'Methods in Enzymology', Vol. 276, 'Macromolecular Crystallography', Part A, Eds. C. W. Carter Jr., R. M. Sweet, Academic Press, New York, 1997, p. 307.
[33] J. de Meulenaer, H. Tompa, *Acta Crystallogr.* **1965**, *19*, 1014.
[34] R. H. Blessing, *Acta Crystallogr., Sect. A* **1995**, *51*, 33.
[35] G. M. Sheldrick, *Acta Crystallogr., Sect. A* **1990**, *46*, 467.
[36] A. Altomare, G. Cascarano, C. Giacovazzo, A. Guagliardi, M. C. Burla, G. Polidori, M. Camalli, 'SIR92', *J. Appl. Crystallogr.* **1994**, *27*, 435.

[37] A. L. Spek, 'PLATON', Program for the Analysis of Molecular Geometry, University of Utrecht, The Netherlands, 2003.
[38] a) E. N. Maslen, A. G. Fox, M. A. O'Keefe, in 'International Tables for Crystallography', Ed. A. J. C. Wilson, Kluwer Academic Publishers, Dordrecht, 1992, Vol. C, Table 6.1.1.1, p. 477; b) D. C. Creagh, W. J. McAuley, in 'International Tables for Crystallography', Ed. A. J. C. Wilson, Kluwer Academic Publishers, Dordrecht, 1992, Vol. C, Table 4.2.6.8, p. 219; c) D. C. Creagh, J. H. Hubbell, in 'International Tables for Crystallography', Ed. A. J. C. Wilson, Kluwer Academic Publishers, Dordrecht, 1992, Vol. C, Table 4.2.4.3, p. 200.
[39] R. F. Stewart, E. R. Davidson, W. T. Simpson, *J. Chem. Phys.* **1965**, *42*, 3175.
[40] J. A. Ibers, W. C. Hamilton, *Acta Crystallogr.* **1964**, *17*, 781.
[41] G. M. Sheldrick, 'SHELXL97', Program for the Refinement of Crystal Structures, University of Göttingen, Germany, 1997.

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