Synthesis of 3-Acyl-4-alkenylpyrrolidines by Platinum-Catalyzed Hydrative Cyclization of Allenynes

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Dedicated to Professor *Giambattista Consiglio* on the occasion of his 65th birthday

A series of nitrogen-tethered allenynes ('5-aza-1,2-dien-7-ynes') **1** were transformed to the corresponding 3-acyl-4-alkenylpyrrolidines **3** when treated with a catalytic amount of $PtCl_2$ in MeOH at 70°. Initial Pt-promoted cyclization forms a nonclassical carbocationic intermediate. In contrast to the cycloisomerization in toluene, which produced the bicyclic cyclobutenes **2**, the intermediate is intercepted by addition of an oxygen nucleophile to achieve the formal hydrative cyclization.

Introduction. – The cycloisomerization of enynes catalyzed by electrophilic transition-metal salts or complexes has received significant attention in recent years because these reactions give rise to structurally highly diverse products, depending on the tethers connecting the enynes, substituents, catalysts, and reaction conditions [1]. The enyne cycloisomerization is generally thought to proceed through intermediates of carbocationic and/or cyclopropylcarbenoid characters. It would provide a useful method to prepare more densely functionalized cyclic compounds if such an intermediate is subsequently intercepted with an intramolecular unsaturated functionality [2] or by another molecule [3].

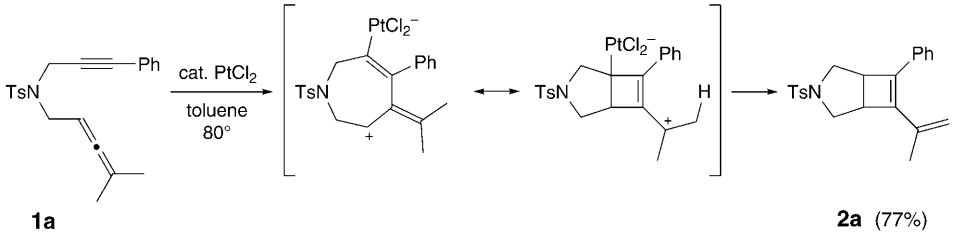
We have been studying the cycloisomerization of allenynes (1,2-dien-7-ynes) expecting reactivities different from those of enynes [4][5][1]), and recently found that heteroatom-tethered allenynes of type **1** undergo a Pt-catalyzed cycloisomerization reaction in toluene at 80° to produce the bicyclic cyclobutenes **2** (*Scheme 1*) [6][7][2]). Herein, we report that a formal hydrative cyclization pathway becomes viable with the same allenynes when the Pt-catalyzed reaction is carried out in MeOH.

Results and Discussion. – The tosylamine-tethered allenyne **1a** was heated in MeOH at 70° (bath temperature) in the presence of a catalytic amount of $PtCl_2$ (10 mol-%) for 24 h (*Scheme 2*). After evaporation of the volatile materials, chromatographic isolation on silica gel afforded '3-benzoyl-4-isobutenyl-1-tosylpyrrolidine'

[1]) For cycloisomerizations of allenynes involving β-hydride elimination, see [4], and for [2+2] cycloadditions of allenynes, see [5].

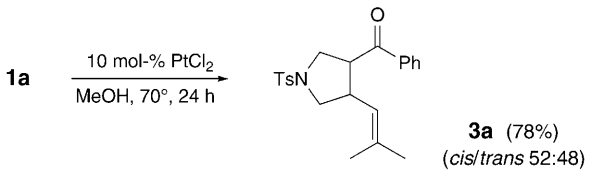
[2]) For the metathesis-type reaction, see [7].

Scheme 1. *Pt-Catalyzed Cycloisomerization of Allenyne* **1a** *to the Bicyclic Cyclobutene* **2a**



(**3a**)[3]) in 78% yield as a separable mixture of the corresponding *cis*- and *trans*-isomers in a ratio of 52 : 48. No cyclobutene derivative, which had been observed in the reaction run in toluene, was detected by ^{1}H-NMR in the crude mixture. When the alternative product, cyclobutene **2a** (*Scheme 1*), was heated in MeOH at 70° in the presence of $PtCl_2$, no **3a** was formed. This suggests that **2a** is not involved in the pathway leading to **3a**. The reaction with AuCl (10 mol-%) was sluggish and gave **3a** only in 14% yield. Other metal salts like $InCl_3$ and $YbCl_3$ failed to exhibit any catalytic activity.

Scheme 2



The following mechanism is conceivable for the formation of **3a** from the allenyne **1a** in MeOH solution (*Scheme 3*). Initially, the alkyne moiety of **1a** coordinates to $PtCl_2$ to form the alkyne–Pt complex **A**. The latter then undergoes an *endo* cyclization with the proximal allenic C=C bond to form the seven-membered ring intermediate **B** (just as is the case in toluene). The cationic intermediate **B** is viewed as a nonclassical cation, to which the resonance form **C** also contributes. A nucleophile, either MeOH or H_2O, then adds to **C** to give intermediate **D**[4]). We assume that a small amount of H_2O might be formed by dehydration of MeOH, which possibly occurs in the presence of the Pt catalyst [8]. Then, the four-membered ring of **D** is opened through β-carbon elimination [9] to afford the alkenylplatinum(II) species **E**[4]). Finally, reductive elimination from **E** furnishes the enol derivative **4**, which leads to the formal hydration product **3** in the presence of H_2O. When the above reaction was carried out at 40° under otherwise identical conditions, the methyl enol ether **4** (R = Me) was isolated in 25% yield, which supports this species being a true intermediate[5]).

When the above reaction was performed in CD_3OD, [D_2]-**3a** was obtained, with one D-atom each in α- and vinylic position (*Scheme 4*). The degree of deuterium incorpo-

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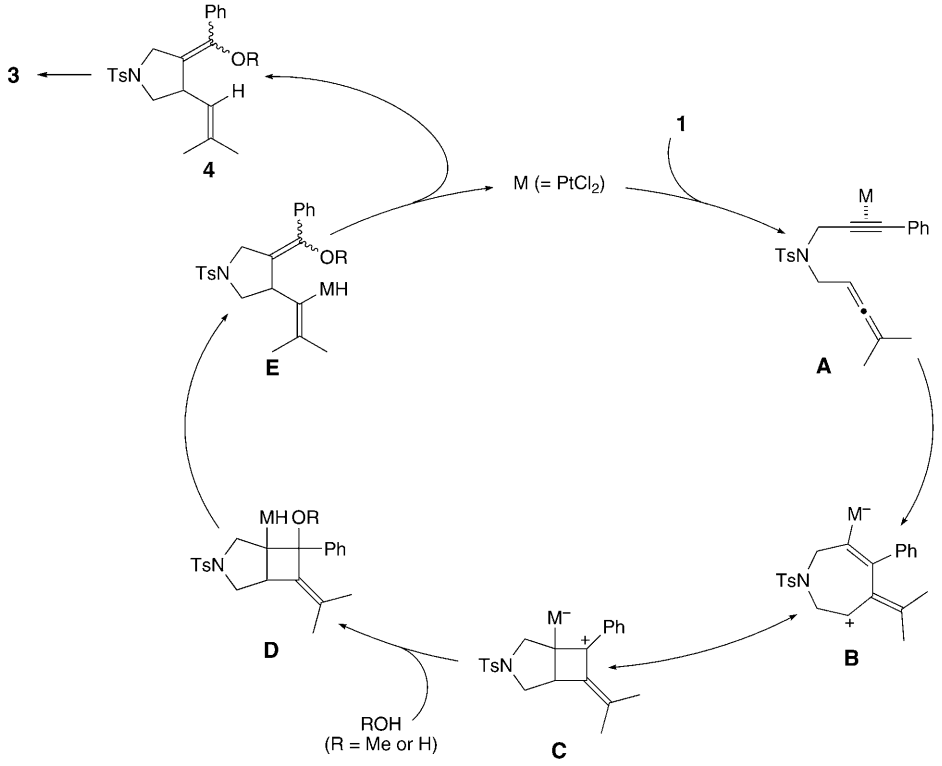
[3]) For systematic names, see the *Exper. Part.*

[4]) Species **D** and **E** are formally depicted as hydride complexes.

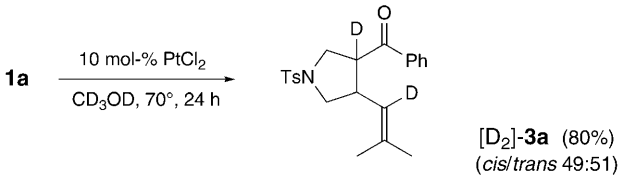
[5]) Obtained as a mixture of stereoisomers (*E*/*Z*) 4:1).

Scheme 3. *Proposed Catalytic Cycle for the Reaction of* **1** *in MeOH*



ration was >96% for both positions. The high deuterium content in α-position to the C=O group was rationalized by assuming that D_2O was present in the reaction medium to convert **4** to **3**.[6])

Scheme 4



Next, we studied the effect of solvent on the reaction of **1a** (*Table 1*). When reacted in the presence of 10 equiv. of MeOH in toluene at 70°, not **3a**, but cyclobutene **2a** was obtained exclusively, suggesting that a large amount of MeOH is required for its formation (*Table 1*, *Entry 1*). The cyclization of **1a** to **3a** also occurred in protic solvents other

[6]) The intermediacy of the corresponding dimethyl acetal cannot be ruled out, although it has not been isolated under any conditions in the reaction of **1a**.

than MeOH, but with less efficiency. In EtOH, *e.g.*, the yield was only 42% (*Entry 3*). The effect of the amount of H_2O on the reaction was also examined. Whereas MeOH/H_2O 100 : 1 served as a medium of comparable efficiency (*Entry 4*), higher proportions of H_2O decreased the product yield (*Entry 5*)[7]).

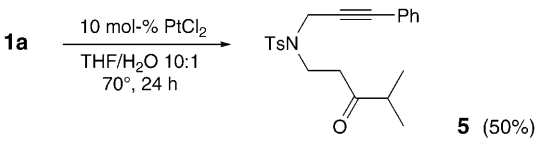
Table 1. *Solvent Effects in the $PtCl_2$-Catalyzed Reaction of* **1a**

Entry	Solvent	Product	Yield [%]	*cis*/*trans*[a])
1	Toluene[b])	**2a**	70	–
2	MeOH	**3a**	78	42 : 48
3	EtOH	**3a**	42	51 : 49
4	MeOH/H_2O 100 : 1	**3a**	71	51 : 49
5	MeOH/H_2O 10 : 1	**3a**	36	49 : 51

[a]) Determined by ^{1}H-NMR. [b]) Containing 10 equiv. of MeOH (rel. to **1a**).

To obtain further information on the role of H_2O, the reaction was carried out in the presence of 3-Å molecular sieves, which should remove any trace of H_2O from the reaction medium. Under these conditions, neither **3a** nor **2a** were formed, and **1a** was recovered. At present, it remains unclear how a small amount of H_2O mechanistically operates. Interestingly, the reaction carried out in THF/H_2O 10 : 1 furnished the open-chain ketone **5** in 50% yield, arising from formal addition of H_2O to the central allenic C-atom (*Scheme 5*). We, thus, conclude that the activation mode of the allenyne **1a** by $PtCl_2$ varies dramatically with the reaction medium.

Scheme 5

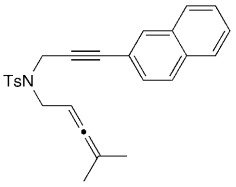
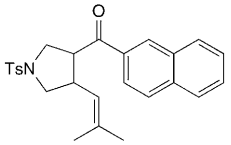
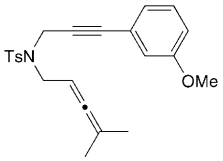
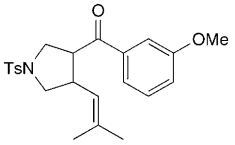
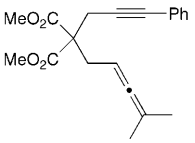
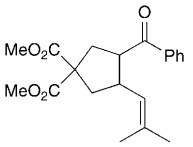
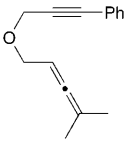
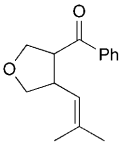
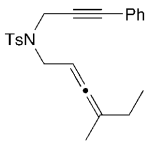
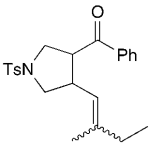
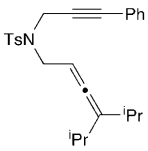


We also tested other allenynes, and the results are summarized in *Table 2*. The 2-naphthyl and 3-anisyl derivatives **1b** and **1c** similarly underwent the cyclization to afford the corresponding products **3b** and **3c**, respectively, as 1 : 1 mixtures of stereoisomers (*Entries 1* and *2* in *Table 2*). Whereas the carbon-tethered allenyne **1d** also gave the cyclopentane derivative **3d** in 66% yield (*Entry 3*), the oxygen-tethered allenyne **1e** afforded an inseparable mixture of products, which contained *ca.* 10% of **3e** (*Entry 4*). The reaction of the allenyne **1f**, with an unsymmetrically substituted allene terminus, gave rise to all four possible isomers (*cis*/*trans* 51 : 49, (*E*/*Z*) 1.3 : 1 for both isomers; *Entry 5*). The allenyne **1g**, having two bulky i-Pr groups, failed to undergo the cyclization, probably due to steric reasons (*Entry 6*).

The reaction of **1h**, carrying a terminal alkyne, gave a mixture of the open-chain product **6** (38%) and the cyclization product **7** (36%), as shown in *Scheme 6*. The ter-

[7]) The use of toluene/H_2O 1 : 1 or EtOH/H_2O 10 : 1 resulted in the formation of a complex mixture.

Table 2. *Hydrative Cyclization of Allenynes* **1b–g** *Catalyzed by* $PtCl_2$ *in MeOH*

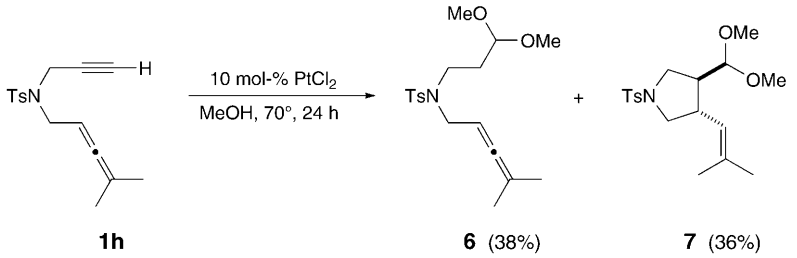
Entry	Series	Starting material (**1**)	Product (**3**)	Isolated yield [%]	*cis*/*trans*[a])
1	**b**			91	49:51
2	**c**			72	49:51
3	**d**			66	48:52
4	**e**			10[b])	–
5	**f**			63	51:49
6	**g**			0	–

[a]) Determined by ^{1}H-NMR. [b]) Estimated by ^{1}H-NMR.

minal alkyne moiety of **1h** was reactive enough to undergo the Pt-catalyzed double addition of MeOH, giving the former linear acetal **6**. Such an *anti-Markovnikov* addition is rather unusual for Pt^{II} catalysts (*vide infra*). The cyclized product **7** had a *trans*-oriented dimethylacetal and 2-mehylbut-2-enyl group. It can be argued whether **7** is formed by a mechanism similar to that proposed for **3** (see *Scheme 4*). Another mechanistic possibility, however, would involve a sequential, stepwise process triggered by addition of MeOH to the C≡C bond.

A control experiment was carried out with the monoyne **8** (*Scheme 7*). The formal hydration of the C≡C bond occurred, and ketone **9**, the *Markovnikov* adduct, was iso-

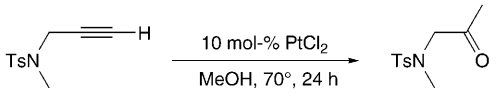
Scheme 6



1h **6** (38%) **7** (36%)

lated in 58% yield [10]. An oxygen nucleophile, either MeOH or H_2O, thus was added regioselectively at the internal position of the propargyl moiety. The formation of the ketone supports the presence of a small amount of H_2O in the reaction medium. Note the opposite regioselectivity in the addition of an oxygen nucleophile to the terminal acetylenic groups of the allenyne **1h** compared to the monoyne **8**. These contrasting results suggest that intramolecular coordination of the allene moiety of **1h** directs the addition site of MeOH to the terminal position of the C≡C bond.

Scheme 7



8 **9** (58%)

Conclusions. – A Pt-catalyzed cyclization reaction of allenynes producing 3-acyl-4-alkenylpyrrolidines has been developed. Changing the solvent from toluene to MeOH directs the reaction pathway from cycloisomerization to formal hydrative cyclization. We have shown that the reaction pattern of allenynes dramatically varies depending on the reaction conditions, particularly on the solvent and its water content.

Experimental Part

General. All manipulations were carried out in a glove box under N_2 atmosphere, or by standard *Schlenk* techniques under Ar atmosphere. $PtCl_2$ was purchased from *Wako Pure Chemical Industries, Ltd*. All other commercially available chemicals were used without further purification. Column chromatography (CC) was performed on silica gel *60 N* (*Kanto*). Prep. thin-layer chromatography (TLC) was performed on silica gel *60 PF_{254}* (*Merck*). NMR Spectra were recorded on a *Varian Gemini-2000* apparatus at 300.77 (^{1}H) or 75.46 MHz (^{13}C); δ in ppm rel. to residual solvent signals ($\delta(CHCl_3)$ 7.26 and 77.00, resp.). High-resolution mass spectra (HR-MS) were recorded on a *JEOL JMS-SX102A* apparatus; in *m*/*z*.

Typical Procedure for the Preparation of Allenynes **1** (outlined for **1a**). To a soln. of (3-phenylprop-2-ynyl)tosylamine (= 4-methyl-*N*-(3-phenylprop-2-yn-1-yl)benzenesulfonamide) (810 mg, 2.84 mmol) [11] in THF (19.0 ml) were added Ph_3P (1.27 g, 4.84 mmol), 4-methylpenta-2,3-dien-1-ol (557 mg, 5.68 mmol) [7], and diisopropyl azodicarboxylate (DIAD; 1.15 g, 5.69 mmol) successively at 0°. The mixture was allowed to warm to r.t. over 30 min, and was then stirred for another 30 min. The solvent was removed

under reduced pressure, and the residue was purified by CC (SiO_2; hexane/AcOEt 14:1) to afford *4-methyl*-N-*(4-methylpenta-2,3-dien-1-yl)*-N-*(3-phenylprop-2-yn-1-yl)benzenesulfonamide* (**1a**; 959 mg, 92%). ^{1}H-NMR: 1.70 (*d*, *J* = 2.7, 6 H); 2.36 (*s*, 3 H); 3.88 (*d*, *J* = 6.9, 2 H); 4.41 (*s*, 2 H); 4.91–4.97 (*m*, 1 H); 7.04 (*d*, *J* = 8.1, 2 H); 7.23–7.33 (*m*, 5 H); 7.71 (*d*, *J* = 8.1, 2 H). ^{13}C-NMR: 20.3; 21.4; 36.5; 46.8; 81.7; 83.7; 85.3; 97.0; 122.3; 127.7; 128.0; 128.2; 129.4; 131.4; 135.9; 143.3; 203.9. HR-EI-MS: 365.1457 (M^+, $C_{22}H_{23}NO_2S^+$; calc. 365.1449).

General Procedure for the Pt-Catalyzed Hydrative Cyclization of Allenynes **1** (outlined for **1a**). To a suspension of $PtCl_2$ (7.6 mg, 0.029 mmol) in MeOH (8.6 ml) was added **1a** (104.5 mg, 0.286 mmol). The mixture was stirred under Ar atmosphere for 24 h at 70°, the volatile material was removed under reduced pressure, and the residue was purified by prep. TLC (SiO_2; hexane/AcOEt 3:1) to afford *3-benzoyl-1-[(4-methylphenyl)sulfonyl]-4-(2-methylprop-1-enyl)pyrrolidine* (**3a**) as a mixture of *cis*- (45.0 mg, 41%) and *trans*-isomers (40.7 mg, 37%).

Data of cis-**3a**. ^{1}H-NMR: 1.12 (*d*, *J* = 1.2, 3 H); 1.29 (*d*, *J* = 0.9, 3 H); 2.45 (*s*, 3 H); 3.06 (*dd*, *J* = 9.9, 4.8, 1 H); 3.32–3.45 (*m*, 1 H); 3.59–3.73 (*m*, 3 H); 4.07 (*q*, *J* = 7.7, 1 H); 4.42 (*dt*, *J* = 10.5, 1.4, 1 H); 7.32–7.55 (*m*, 5 H); 7.70–7.79 (*m*, 4 H). ^{13}C-NMR: 17.5; 21.5; 25.4; 40.6; 48.3; 49.2; 54.0; 120.1; 127.7; 128.0; 128.5; 129.6; 133.0; 133.5; 135.2; 136.9; 143.5; 197.9. HR-FAB-MS: 384.1639 ($[M+H]^+$, $C_{22}H_{26}NO_3S^+$; calc. 384.1628).

Data of trans-**3a**. ^{1}H-NMR: 1.42 (*d*, *J* = 0.9, 3 H); 1.55 (*d*, *J* = 0.9, 3 H); 2.46 (*s*, 3 H); 3.07 (*dd*, *J* = 9.6, 7.8, 1 H); 3.18–3.32 (*m*, 1 H); 3.36–3.44 (*m*, 1 H); 3.46 (*dd*, *J* = 9.5, 7.7, 1 H); 3.62–3.76 (*m*, 2 H); 4.93 (*d*, *J* = 9.3, 1 H); 7.35 (*d*, *J* = 8.1, 2 H); 7.40–7.47 (*m*, 2 H); 7.53–7.60 (*m*, 1 H); 7.73 (*d*, *J* = 8.1, 2 H); 7.82 (*d*, *J* = 7.5, 2 H). ^{13}C-NMR: 18.1; 21.6; 25.6; 41.3; 50.7; 51.3; 53.2; 122.9; 127.6; 128.4; 128.6; 129.7; 133.4; 133.5; 135.8; 136.2; 143.6; 198.1. HR-FAB-MS: 384.1636 ($[M+H]^+$, $C_{22}H_{26}NO_3S^+$; calc. 384.1628).

Data of [3-^{2}H]-3-Benzoyl-1-[(4-methylphenyl)sulfonyl]-4-([1-^{2}H]-2-methylprop-1-enyl)pyrrolidine (*cis*-[D_2]-**3a**). ^{1}H-NMR: 1.12 (*s*, 3 H); 1.29 (*s*, 3 H); 2.45 (*s*, 3 H); 3.06 (*dd*, *J* = 10.1, 5.0, 1 H); 3.37 (*t*, *J* = 5.4, 1 H); 3.60–3.71 (*m*, 3 H); 7.33–7.44 (*m*, 4 H); 7.48–7.55 (*m*, 1 H); 7.72–7.79 (*m*, 4 H). ^{13}C-NMR[8]): 17.5; 21.5; 25.3; 40.5; 48.3; 53.9; 127.7; 128.0; 128.5; 129.6; 133.1; 133.5; 135.1; 136.9; 143.5; 198.0. HR-FAB-MS: 386.1758 ($[M+H]^+$, $C_{22}H_{24}D_2NO_3S^+$; calc. 386.1751).

Data of trans-*[D_2]*-**3a**. ^{1}H-NMR: 1.41 (*s*, 3 H); 1.55 (*s*, 3 H); 2.46 (*s*, 3 H); 3.07 (*dd*, *J* = 9.6, 7.8, 1 H); 3.24 (*t*, *J* = 7.7, 1 H); 3.40 (*d*, *J* = 9.6, 1 H); 3.46 (*dd*, *J* = 9.6, 7.5, 1 H); 3.71 (*d*, *J* = 9.9, 1 H); 7.35 (*d*, *J* = 8.1, 2 H); 7.40–7.47 (*m*, 2 H); 7.53–7.60 (*m*, 1 H); 7.72 (*d*, *J* = 8.1, 2 H); 7.79–7.85 (*m*, 2 H). ^{13}C-NMR[8]): 18.0; 21.6; 25.5; 41.2; 50.6; 53.2; 127.6; 128.4; 128.6; 129.7; 133.4; 133.5; 135.7; 136.2; 143.6; 198.1. HR-FAB-MS: 386.1754 ($[M+H]^+$, $C_{22}H_{24}D_2NO_3S^+$; calc. 386.1751).

Data of cis-*1-[(4-Methylphenyl)sulfonyl]-3-(2-methylprop-1-enyl)-4-[(naphthalen-2-yl)carbonyl]pyrrolidine* (*cis*-**3b**). ^{1}H-NMR: 1.10 (*d*, *J* = 1.2, 3 H); 1.26 (*d*, *J* = 1.2, 3 H); 2.47 (*s*, 3 H); 3.11 (*dd*, *J* = 9.8, 5.3, 1 H); 3.42–3.53 (*m*, 1 H); 3.65–3.80 (*m*, 3 H); 4.25 (*q*, *J* = 7.6, 1 H); 4.49 (*dt*, *J* = 10.5, 1.2, 1 H); 7.37 (*d*, *J* = 7.8, 2 H); 7.51–7.63 (*m*, 2 H); 7.77–7.94 (*m*, 6 H); 8.28 (*s*, 1 H). ^{13}C-NMR: 17.6; 21.6; 25.4; 40.8; 48.5; 49.2; 54.0; 120.2; 123.7; 126.9; 127.7; 128.4; 128.6; 129.4; 129.6; 129.8; 132.3; 133.5; 134.2; 135.3; 135.4; 143.5; 197.9; one arom. signal missing due to overlapping. HR-FAB-MS: 434.1784 ($[M+H]^+$, $C_{26}H_{28}NO_3S^+$; calc. 434.1784).

Data of trans-**3b**. ^{1}H-NMR: 1.41 (*d*, *J* = 1.2, 3 H); 1.55 (*d*, *J* = 1.2, 3 H); 2.47 (*s*, 3 H); 3.08–3.53 (*m*, 4 H); 3.75–3.90 (*m*, 2 H); 5.02 (*dt*, *J* = 9.6, 1.4, 1 H); 7.36 (*d*, *J* = 8.1, 2 H); 7.50–7.65 (*m*, 2 H); 7.75 (*d*, *J* = 8.4; 2 H); 7.84–7.95 (*m*, 4 H); 8.32 (*s*, 1 H). ^{13}C-NMR: 18.1; 21.6; 25.6; 41.5; 50.8; 51.4; 53.3; 123.1; 123.9; 126.9; 127.1; 127.66; 127.72; 128.5; 128.8; 129.5; 129.7; 130.5; 133.4; 133.6; 135.6; 135.8; 143.6; 197.9. HR-FAB-MS: 434.1791 ($[M+H]^+$, $C_{26}H_{28}NO_3S^+$; calc. 434.1784).

Data of cis-*3-[(3-Methoxyphenyl)carbonyl]-1-[(4-methylphenyl)sulfonyl]-4-(2-methylprop-1-enyl)-pyrrolidine* (*cis*-**3c**). ^{1}H-NMR: 1.15 (*d*, *J* = 1.2, 3 H); 1.32 (*d*, *J* = 0.9, 3 H); 2.45 (*s*, 3 H); 3.07 (*dd*, *J* = 10.1, 4.7, 1 H); 3.32–3.43 (*m*, 1 H); 3.58–3.73 (*m*, 3 H); 3.81 (*s*, 3 H); 4.04 (*q*, *J* = 7.8, 1 H); 4.43 (*dt*, *J* = 10.5, 1.3, 1 H); 7.04–7.09 (*m*, 1 H); 7.25–7.29 (*m*, 1 H); 7.30–7.38 (*m*, 4 H); 7.77 (*d*, *J* = 8.4, 2 H).

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[8]) Two signals are missing due to the magnetic relaxation of C–D.

^{13}C-NMR: 17.6; 21.6; 25.5; 40.7; 48.4; 49.4; 54.0; 55.5; 112.5; 119.4; 120.1; 120.6; 127.2; 127.7; 129.5; 129.6; 133.5; 135.3; 138.3; 143.5; 159.8; 197.7. HR-FAB-MS: 414.1745 ($[M+H]^+$, $C_{23}H_{28}NO_4S^+$; calc. 414.1734).

Data of trans-**3c**. ^{1}H-NMR: 1.44 (*d*, *J* = 1.2, 3 H); 1.57 (*d*, *J* = 0.9, 3 H); 2.46 (*s*, 3 H); 3.05 (*dd*, *J* = 9.9, 7.5, 1 H); 3.19–3.32 (*m*, 1 H); 3.40 (*dd*, *J* = 9.0, 7.5, 1 H); 3.47 (*dd*, *J* = 9.8, 7.7, 1 H); 3.58–3.74 (*m*, 2 H); 3.83 (*s*, 3 H); 4.92 (*dt*, *J* = 9.6, 1.5, 1 H); 7.08–7.13 (*m*, 2 H); 7.32–7.38 (*m*, 5 H); 7.73 (*d*, *J* = 8.1, 2 H). ^{13}C-NMR: 18.1; 21.6; 25.6; 41.3; 50.7; 51.5; 53.2; 55.4; 112.7; 119.9; 121.0; 122.9; 127.6; 129.5; 129.7; 133.4; 135.8; 137.6; 143.6; 159.8; 197.9. HR-FAB-MS: 414.1737 ($[M+H]^+$, $C_{23}H_{28}NO_4S^+$; calc. 414.1734).

Data of Dimethyl cis-*3-Benzoyl-4-(2-methylprop-1-enyl)cyclopentane-1,1-dicarboxylate* (*cis*-**3d**). ^{1}H-NMR: 1.25 (*d*, *J* = 1.2, 3 H); 1.37 (*d*, *J* = 1.2, 3 H); 2.21 (*dd*, *J* = 13.8, 8.4, 1H); 2.48 (*ddd*, *J* = 7.3, 4.1, 1.2, 1 H); 2.52 (*ddd*, *J* = 7.3, 3.9, 1.2, 1 H); 2.82 (*dd*, *J* = 14.1, 8.7, 1 H); 3.31–3.44 (*m*, 1 H); 3.78 (*s*, 2×3 H); 4.01–4.11 (*m*, 1 H); 4.79 (*dt*, *J* = 10.5, 1.4, 1 H); 7.38–7.44 (*m*, 2 H); 7.47–7.54 (*m*, 1 H); 7.80–7.85 (*m*, 2 H). ^{13}C-NMR: 17.7; 25.4; 35.5; 40.6; 40.8; 49.4; 52.8; 52.9; 59.4; 123.8; 128.2; 128.3; 132.6; 133.4; 137.7; 172.0; 173.2; 200.6. HR-EI-MS: 344.1621 (M^+, $C_{20}H_{24}O_5^+$; calc. 344.1624).

Data of trans-**3d**. ^{1}H-NMR: 1.46 (*d*, *J* = 0.9, 3 H); 1.54 (*d*, *J* = 0.9, 3 H); 1.90 (*dd*, *J* = 13.7, 10.4, 1 H); 2.44 (*dd*, *J* = 13.8, 9.9, 1 H); 2.72 (*dd*, *J* = 8.1, 4.5, 1 H); 2.76 (*dd*, *J* = 8.1, 4.5, 1 H); 3.21–3.35 (*m*, 1 H); 3.60–3.72 (*m*, 1 H); 3.75 (*s*, 3 H); 3.76 (*s*, 3 H); 4.97 (*d*, *J* = 9.6, 1 H); 7.40–7.47 (*m*, 2 H); 7.51–7.58 (*m*, 1 H); 7.89–7.94 (*m*, 2 H). ^{13}C-NMR: 18.1; 25.6; 38.3; 41.1; 42.6; 52.4; 52.8; 52.9; 59.2; 125.7; 128.3; 128.5; 133.0; 134.2; 137.0; 172.0; 172.8; 200.7. HR-EI-MS: 344.1621 (M^+, $C_{20}H_{24}O_5^+$; calc. 344.1624).

*Data of (*E/Z*)*-cis-3-*Benzoyl-4-(2-methylbut-1-enyl)-1-[(4-methylphenyl)sulfonyl]pyrrolidine* (*cis*-**3f**). ^{1}H-NMR: 0.57 (one isomer, *t*, *J* = 7.4, 3 H); 0.59 (another isomer, *t*, *J* = 7.5, 3 H); 1.12 (one isomer, *d*, *J* = 1.2, 3 H); 1.30 (another isomer, *d*, *J* = 1.5, 3 H); 1.47–1.75 ((*E*)- and (*Z*)-isomers, *m*, 2× 2 H); 2.45 ((*E*)- and (*Z*)-isomers, *s*, 2×3 H); 3.00–3.10 ((*E*)- and (*Z*)-isomers, *m*, 2×1 H); 3.34–3.47 ((*E*)- and (*Z*)-isomers, *m*, 2×1 H); 3.60–3.74 ((*E*)- and (*Z*)-isomers, *m*, 2×2 H); 4.02–4.15 ((*E*)- and (*Z*)-isomers, *m*, 2×1 H); 4.41 ((*E*)- and (*Z*)-isomers, *d*, *J* = 9.9, 2×1 H); 7.32–7.43 ((*E*)- and (*Z*)-isomers, *m*, 2×4 H); 7.48–7.55 ((*E*)- and (*Z*)-isomers, *m*, 2×1 H); 7.73–7.80 ((*E*)- and (*Z*)-isomers, *m*, 2×4 H). ^{13}C-NMR: 12.1; 12.4; 15.7; 21.6; 22.5; 24.5; 32.1; 40.2; 40.4; 48.3; 48.4; 49.09; 49.15; 53.9; 54.3; 118.6; 119.5; 127.7; 128.0; 128.1; 128.46; 128.49; 129.6; 133.1; 133.5; 136.7; 136.9; 140.6; 140.7; 143.5; 197.9; some signals were overlapped. HR-FAB-MS (mixture): 398.1791 ($[M+H]^+$, $C_{23}H_{28}NO_3S^+$; calc. 398.1784).

Data of trans-**3f**. ^{1}H-NMR: 0.77 (one isomer, *t*, *J* = 7.4, 3 H); 0.82 (another isomer, *t*, *J* = 7.2, 3 H); 1.40 (one isomer, *s*, 3 H); 1.55 (another isomer, *d*, *J* = 1.2, 3 H); 1.67–1.97 ((*E*)- and (*Z*)-isomers, *m*, 2×2 H); 2.46 ((*E*)- and (*Z*)-isomers, *s*, 2×3 H); 3.03–3.16 ((*E*)- and (*Z*)-isomers, *m*, 2×1 H); 3.18–3.32 ((*E*)- and (*Z*)-isomers, *m*, 2×1 H); 3.37–3.51 ((*E*)- and (*Z*)-isomers, *m*, 2×2 H); 3.62–3.76 ((*E*)- and (*Z*)-isomers, *m*, 2×1 H); 4.86–4.96 ((*E*)- and (*Z*)-isomers, *m*, 2×1 H); 7.35 ((*E*)- and (*Z*)-isomers, *d*, *J* = 8.1, 2×2 H); 7.40–7.48 ((*E*)- and (*Z*)-isomers, *m*, 2×2 H); 7.53–7.60 ((*E*)- and (*Z*)-isomers, *m*, 2×1 H); 7.71–7.76 ((*E*)- and (*Z*)-isomers, *m*, 2×2 H); 7.80–7.85 ((*E*)- and (*Z*)-isomers, *m*, 2×2 H). ^{13}C-NMR: 12.4; 12.9; 16.3; 21.6; 22.7; 25.0; 29.7; 32.1; 41.0; 41.4; 50.7; 50.8; 51.38; 51.42; 53.4; 53.5; 121.3; 122.4; 127.7; 128.5; 128.57; 128.60; 129.7; 133.4; 133.50; 133.55; 136.27; 136.35; 141.3; 141.4; 143.6; 198.0; 198.3; some signals were overlapped. HR-FAB-MS (mixture): 398.1789 ($[M+H]^+$, $C_{23}H_{28}NO_3S^+$; calc. 398.1784).

*Data of (3*E*)-3-[(Methoxy)(phenyl)methylidene)-1-[(4-methylphenyl)sulfonyl]-4-(2-methylprop-1-enyl)pyrrolidine* (**4**, R = Me). ^{1}H-NMR: 1.27 (*d*, *J* = 1.2, 3 H); 1.38 (*d*, *J* = 1.2, 3 H); 2.43 (*s*, 3 H); 2.87 (*dd*, *J* = 9.2, 5.0, 1 H); 3.31 (*s*, 3 H); 3.34 (*dd*, *J* = 9.2, 7.1, 1 H); 3.44–3.53 (*m*, 1 H); 3.94 (*dd*, *J* = 14.6, 1.7, 1 H); 4.13 (*d*, *J* = 14.7, 1 H); 4.69 (*dt*, *J* = 9.9, 1.4, 1 H); 7.13–7.18 (*m*, 2 H); 7.23–7.29 (*m*, 3 H); 7.33 (*d*, *J* = 8.1, 2 H); 7.73 (*d*, *J* = 8.4, 2 H). ^{13}C-NMR: 17.5; 21.5; 25.3; 39.2; 49.9; 55.0; 57.0; 121.3; 124.3; 127.8; 128.0; 128.1; 128.8; 129.5; 132.0; 132.3; 133.4; 143.4; 148.7. HR-EI-MS: 397.1706 (M^+, $C_{23}H_{27}NO_3S^+$; calc. 397.1706).

4-Methyl-N-*(4-methyl-3-oxopentyl)*-N-*(3-phenylprop-2-yn-1-yl)benzenesulfonamide* (**5**). ^{1}H-NMR: 1.09 (*d*, *J* = 6.9, 6 H); 2.32 (*s*, 3 H); 2.60 (*sept.*, *J* = 6.9, 1 H); 2.90 (*t*, *J* = 6.6, 2 H); 3.47 (*t*, *J* = 6.9, 2 H); 4.34 (*s*, 2 H); 7.06 (*dd*, *J* = 7.8, 1.5, 2 H); 7.18–7.27 (*m*, 5 H); 7.76 (*d*, *J* = 8.1, 2 H). ^{13}C-NMR: 18.1; 21.4; 38.9; 40.0; 41.1; 42.4; 82.1; 85.4; 122.1; 127.8; 128.1; 128.4; 129.5; 131.4; 135.4; 143.6; 212.7. HR-FAB-MS: 384.1634 ($[M+H]^+$, $C_{22}H_{26}NO_3S^+$; calc. 384.1628).

N-*(3,3-Dimethoxypropyl)-4-methyl*-N-*(4-methylpenta-2,3-dien-1-yl)benzenesulfonamide* (**6**). ^{1}H-NMR: 1.63 (*d*, *J* = 3.0, 6 H); 1.87 (*q*, *J* = 6.8, 2 H); 2.41 (*s*, 3 H); 3.22 (*t*, *J* = 7.5, 2 H); 3.31 (*s*, 6 H); 3.76

(*d*, *J* = 6.9, 2 H); 4.40 (*t*, *J* = 5.4, 1 H); 4.64–4.74 (*m*, 1 H); 7.28 (*d*, *J* = 8.1, 2 H); 7.69 (*d*, *J* = 8.1, 2 H). ^{13}C-NMR: 20.2; 21.5; 31.6; 42.7; 48.1; 53.2; 84.3; 96.8; 102.5; 127.1; 129.6; 137.0; 143.1; 203.3. HR-FAB-MS: 353.1661 (M^+, $C_{18}H_{27}NO_4S^+$; calc. 353.1655).

trans-*3-(Dimethoxymethyl)-1-[(4-methylphenyl)sulfonyl]-4-(2-methylprop-1-en-1-yl)pyrrolidine* (**7**). ^{1}H-NMR: 1.57 (*d*, *J* = 1.2, 3 H); 1.63 (*d*, *J* = 1.5, 3 H); 2.06 (*quint.*, *J* = 7.3, 1 H); 2.43 (*s*, 3 H); 2.72 (*dd*, *J* = 9.4, 8.3, 1 H); 2.78 (*quint.*, *J* = 8.1, 1 H); 3.20 (*s*, 3 H); 3.22 (*dd*, *J* = 10.3, 7.1, 1 H); 3.26 (*s*, 3 H); 3.27 (*dd*, *J* = 10.4, 8.2, 1 H); 3.43 (*dd*, *J* = 8.7, 6.6, 1 H); 4.06 (*d*, *J* = 6.0, 1 H); 4.78 (*dd*, *J* = 9.2, 1.4, 1 H); 7.32 (*d*, *J* = 7.8, 2 H); 7.70 (*d*, *J* = 8.4, 2 H). ^{13}C-NMR: 18.0; 21.5; 25.7; 39.3; 47.5; 48.5; 53.3; 53.4; 54.9; 105.1; 123.8; 127.7; 129.5, 133.3; 134.3; 143.3. HR-FAB-MS: 354.1739 ($[M+H]^+$, $C_{18}H_{28}NO_4S^+$; calc. 354.1734).

N,*4-Dimethyl*-N-*(2-oxopropyl)benzenesulfonamide* (**9**). ^{1}H-NMR: 2.21 (*s*, 3 H); 2.43 (*s*, 3 H); 2.78 (*s*, 3 H); 3.83 (*s*, 2 H); 7.32 (*d*, *J* = 8.1, 2 H); 7.67 (*d*, *J* = 8.1, 2 H). ^{13}C-NMR: 21.6; 27.0; 36.1; 59.4; 127.4; 129.7; 134.4; 143.7; 203.6. HR-FAB-MS: 242.0851 ($C_{11}H_{16}NO_3S^+$; calc. 242.0845).

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