# 3-Cyclopropyl- and 3-*tert*-Butyl-Substituted Propyne Iminium Salts as Dienophiles in Diels–Alder Reactions

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Dedicated to Professor Dieter Hoppe on the occasion of his 65th birthday

**Abstract:** Starting from cyclopropylacetylene and 3,3-dimethylbut-1-yne, and an imidoyl chloride **5**, the alkynyl imines **6** were prepared and then converted into propyne iminium triflates **7** by N-methylation. These electron-deficient acetylenes were found to be reactive dienophiles in Diels–Alder reactions with cyclopentadiene, furan, 2,3-dimethylbuta-1,3-diene, and anthracene. Reduction of the iminium function, which is present in the cycloaddition products, generates tertiary amines. In this manner, norbornadiene (**8**, **9**), 7-oxanorbornadiene (**10**, **11**), cyclohexa-1,4-diene (**12**), benzene (**13**, **14**), and dibenzobarrelene (**15**, **16**) derivatives with a novel vicinal substitution pattern were obtained.

**Key words:** alkynes, imines, iminium salts, cycloadditions, Diels–Alder reactions

Cycloaddition reactions of acetylenic iminium salts provide a convenient approach to carbo- and heterocyclic ring systems bearing a reactive iminium substituent, which offers different opportunities for further transformation. In fact, we have observed earlier that propyne iminium salts **1a–c**[1,2] and **2a–c**[2] (Figure 1) can serve as dienophiles in Diels–Alder reactions with common acyclic and cyclic 1,3-dienes. However, in spite of the activation of the acetylenic bond by the electron-withdrawing iminium function, these reactions proceed rather slowly (e.g., with cyclopentadiene in toluene: 20–72 h at 20 °C; with anthracene: 7–12 h at 120 °C for **2a–c**, 26–69 h at 110 °C for **1a**,**c**). Although no quantitative kinetic comparison was made, it appeared that the trimethylsilyl-substituted propyne iminium salts **2** reacted more smoothly, and also in better yield, than their phenyl-substituted relatives **1** with the less reactive diene moiety of anthracene. On the other hand, it was reported that propyne amidinium salts **3** undergo a smooth [4+2] cycloaddition with cyclopentadiene[3] and buta-1,3-diene[4] when $R^3$ = H, but the reaction rate is strongly decreased when $R^3$ = Ph or *t*-Bu.[3]

These observations suggest that the dienophilic character of acetylenic iminium salts very much depends on both electronic and steric effects. Under both aspects, branched alkyl groups, such as cyclopropyl and *tert*-butyl, as substituents at the C≡C bond did not appear to be a good choice for successful Diels–Alder reactions. As we report

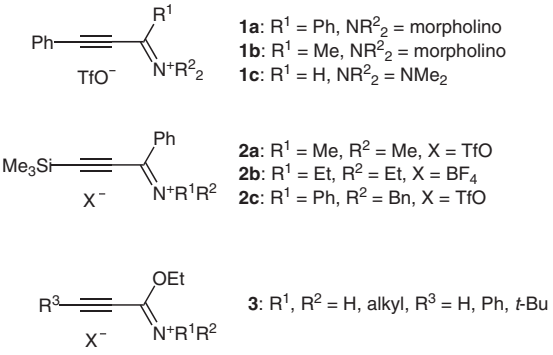


**Figure 1**

now, both types of propyne iminium salts do react quite well, giving rise to carbo- and heterocyclic systems with a novel vicinal substitution pattern.

The novel propyne iminium triflates **7** were obtained by an approach via alkynyl imines which we had developed earlier.[5] Starting from cyclopropylacetylene (**4a**) and 3,3-dimethylbut-1-yne (**4b**), and arene imidoyl chlorides **5**, the alkynyl imines **6** were synthesized (Scheme 1). In order to optimize the yields of the coupling reaction, several variations were first tested for the combination of **4a** with **5a** ($R^1$ = Ph, $R^3$ = Me). By far the best yield was obtained from the Cu(I)-catalyzed coupling reaction using the alkynyl Grignard derivative of **4a** (Table 1). In the absence of the copper salt, the yield was rather low, in contrast to the analogous reaction of trimethylsilylacetylene or 1-hexyne with **5a**.[5,6] Notably, the direct palladium-catalyzed coupling of **4a** under Sonogashira-type conditions produced rather disappointing results, in contrast to literature reports where analogous reactions of other 1-alkynes and imidoyl chlorides were described.[5,7] Effective Sonogashira coupling of terminal alkynes with some cyclic imidoyl halide functionalities has also been reported, e.g., the coupling between **4a** and 2-bromo-1,3-thiazole[8] or between phenylacetylene and 5-chloro-1,3-dihydro-1,4-benzodiazepin-2(2*H*)ones.[9] Using the organocopper route, alkynyl imines **6a–p** could be prepared in yields of 41–81%, while the preparation of 2-furyl-substituted derivative **6q** suffered from significant loss of material during work up (Table 2).

Selected *N*-methyl alkynyl imines **6** were then converted into *N*,*N*-dimethyl alkynyl iminium triflates **7** with methyl triflate (Scheme 1 and Tables 3 and 4). The crystalline solids obtained after recrystallization can be stored without problems provided that moisture is excluded.

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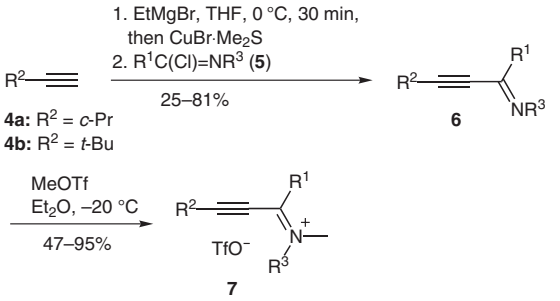


**Scheme 1** Synthesis of alkynyl imines **6** and propyne iminium triflates **7**; for $R^1$–$R^3$, see Tables 2 and 3

[4+2]-Cycloaddition reactions of several 1,3-dienes with the alkynyl iminium salts **7a**,**b**,**l**,**n**,**p** were investigated next (Scheme 2 and Table 5). The reactions with cyclopentadiene and furan proceeded at moderate temperatures and gave the bicyclo[2.2.1]hepta-2,5-diene systems **8** and **10**, respectively. Reactions with furan were carried out in the temperature range 40–46 °C in order to avoid the formation of unspecific side or decomposition products which was observed at higher temperatures. Oxanorbornadiene derivatives **10a**,**l**,**n** were observed to decompose at their melting points; a closer inspection for **10a** showed that the retro-Diels–Alder reaction took place to furnish **7a** and furan.

Cycloaddition reactions with 2,3-dimethylbuta-1,3-diene gave the 1,4-cyclohexadien-1-yl iminium salts **12** which could be isolated in mostly good yields. Under the given conditions, including the exclusion of air, partial dehydrogenating aromatization, leading to arene iminium salts **13**, was not a problem, although **12l**,**n** showed a tendency to aromatize on heating when oxygen was not rigorously excluded. This enhanced reactivity was exploited for the direct synthesis of **13l** from **7l**, carrying out the [4+2] cycloaddition in the presence of air. The conversion **12a** → **13a** was achieved using established procedures. The Diels–Alder reaction of **7a** and anthracene required the most forcing conditions, which were similar to those for 3-phenyl-substituted propyne iminium salt **1a** (see introduction), yielding dibenzobarrelene derivative **15a** almost quantitatively.

As expected, the presence of a *tert*-butyl substituent instead of cyclopropyl considerably slowed down the reaction rate for steric reasons. The decreased reaction rates, which are observed when the iminium carbon atom carries a 4-methoxyphenyl or 4-tolyl rather than a phenyl substituent, can be attributed to a better charge stabilization which raises the LUMO energy of the dienophile.

$^1$H and $^{13}$C NMR data of cycloaddition products **8**, **10**, **12**, **13**, **15** are presented in Table 6. The spectra of **8b** show two sets of signals, the ratio of which is slightly temperature-dependent (in DMSO-$d_6$, 300 K: 59.5:40.5; 375 K: 57:43). It is reasonable to assume the presence of two atropisomers, caused by hindered rotation about the C($sp^2$, norbornadiene)–C(=$N^+Me_2$) single bond. We have observed this before in a structurally similar case, where steric interaction of the iminium moiety with a $SiMe_3$ rather than a *tert*-butyl group was the reason for hindered rotation. NOE experiments suggest that the dominating isomer has the iminium group in an *endo* orientation with respect to the norbornadiene framework, while an *exo* orientation (*endo*-phenyl orientation) is found in the minor isomer.

**Table 1** Conditions and Yields for the Coupling Reaction **4a** + **5a** → **6a**

| Conditions | Yield (%) |
|---|---|
| **4a**[a] + BuLi (1.5 equiv), $Et_2O$, 0 °C, then **5a**, 0 °C | 18 |
| **4a**[a] + MeMgBr (1 equiv), THF, 0 °C, then **5a**, 0 °C | 20 |
| **4a**[a] + MeMgBr (1 equiv), CuBr·$Me_2S$ (0.05 equiv), THF, 0 °C, then **5a**, 0 °C | **67** |
| **4a**[a] + **5a**, $Pd(PPh_3)_2Cl_2$ (3 mol%), CuI (10 mol%), $Et_3N$ (solvent), 70 °C, 7 h | 20[b] |
| **4a**[a] + **5a**, $Pd(dba)_2$ (3 mol%), P(*t*-Bu)$_3$ (6 mol%), $Et_3N$ (1.2 equiv), dioxane, 70 °C, 7 h | 5 |

[a] A 70% solution in toluene was used.
[b] Similar or even lower yields were obtained using several variations of this method [e.g., dioxane as solvent, $Et_3N$ (1.2 equiv), $Cs_2CO_3$ (1.2 equiv), or $K_3PO_4$ (1.0 equiv) as bases].

The cycloaddition products **8**, **10**, **12**, **13** and **15** still contain a reactive iminium function, which offers opportunities for several different transformations. We show here exemplarily the conversion into tertiary amines using lithium aluminium hydride as the reducing agent. Amines **9a**, **14a** and **16a** were so obtained in yields of 69–98%, while the oxanorbornadiene-substituted iminium salt **10a** did not react selectively and furnished amine **11a** only in ~20% yield besides several other products. Efforts to optimize this transformation are underway. Both **9a** and **11a** were obtained as a mixture of diastereomers in 61:39 and 60:40 ratios, respectively. However, reduction of **8a** with L-Selectride changed the diasteromeric ratio for **9a** to 91:9.

In conclusion, we have shown that both 3-cyclopropyl- and 3-*tert*-butyl-substituted propyne iminium salts are suitable dienophiles for the Diels–Alder reaction of more (cyclopentadiene, furan, 2,3-dimethylbuta-1,3-diene) or less (anthracene) reactive 1,3-diene moieties. The iminium group in the resulting cycloaddition products provides a handle for various further transformations, as shown here exemplarily for the hydride reduction providing a tertiary amine function. The vicinal cyclopropyl/dialkylaminomethyl substitution pattern obtained after reduction of the cycloadducts is a novel one. The synthetic transformations presented in this paper have outlined a novel application of cyclopropylacetylene as a building block which, with the [4+2] cycloaddition of 3-cyclopropylpropyne iminium salts as the key step, allows a convenient introduction of the cyclopropyl substituent at six-membered carbo- and heterocyclic ring systems. Similar cycloaddition chemistry has been described for methyl 3-(1-chlorocyclopropyl)propynoate, which, however, undergoes the Diels–Alder reaction more reluctantly than propyne iminium triflates **7**. Methyl 3-cyclopropylpropyonate, on the other hand, does not react with cyclopentadiene up to 180 °C.[10]



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**Table 2** Alkynyl Imines **6** Prepared (Scheme 1) and Selected IR Data

| Product | $R^1$ | $R^2$ | $R^3$ | Molecular formula | Yield[a] (%) | Mp (°C) or bp (°C/mbar)[b] | IR[c] ($cm^{-1}$) $\nu_{C\equiv C}$ | other signals |
|---|---|---|---|---|---|---|---|---|
| **6a** | Ph | *c*-$C_3H_5$ | Me | $C_{13}H_{13}N$ (183.25) | 66 | 135/0.03 | 2210 | 1593, 1572, 1282, 921, 692 |
| **6b** | Ph | *t*-Bu | Me | $C_{14}H_{17}N$ (199.29) | 77 | 100/0.001 | 2216 | 1595, 1574, 1292, 774, 693 |
| **6c** | Ph | *c*-$C_3H_5$ | Et | $C_{14}H_{15}N$ (197.28) | 73 | 115/0.001[d] | 2216 | 1591, 1567, 1281, 931, 692 |
| **6d** | Ph | *t*-Bu | Et | $C_{15}H_{19}N$ (213.32) | 80 | 110/0.001 | 2217 | 1592, 1571, 1287, 773, 692 |
| **6e** | Ph | *c*-$C_3H_5$ | Bn | $C_{19}H_{17}N$ (259.35) | 81 | Oil[d] | 2214 | 1593, 1568, 1280, 919, 691 |
| **6f** | Ph | *t*-Bu | Bn | $C_{20}H_{21}N$ (275.39) | 67 | Oil[d] | 2214 | 1594, 1569, 1288, 921, 693 |
| **6g** | Ph | *c*-$C_3H_5$ | Cy | $C_{18}H_{21}N$ (251.37) | 76 | 40–41; 180/0.001 | 2211 | 1591, 1567, 1256, 776, 695 |
| **6h** | Ph | *t*-Bu | Cy | $C_{19}H_{25}N$ (267.41) | 69 | 140/0.001 | 2217 | 1592, 1567, 1285, 773, 692 |
| **6i** | Ph | *c*-$C_3H_5$ | Bu | $C_{16}H_{19}N$ (225.33) | 46 | 150/0.001 | 2215 | 1592, 1569, 1280, 773, 692 |
| **6j** | Ph | *c*-$C_3H_5$ | Pr | $C_{15}H_{17}N$ (211.31) | 55 | 160/0.001 | 2214 | 1592, 1569, 1281,773, 692 |
| **6k** | Ph | *t*-Bu | Pr | $C_{16}H_{21}N$ (227.35) | 44 | 120/0.001 | 2217 | 1593, 1571, 1287, 773, 692 |
| **6l** | $C_6H_4$-4-OMe | *c*-$C_3H_5$ | Me | $C_{14}H_{15}NO$ (213.28) | 45 | 135/0.001 | 2211 | 1605, 1591, 1569, 1509, 1247, 1167, 1030, 921 |
| **6m** | $C_6H_4$-4-OMe | *t*-Bu | Me | $C_{15}H_{19}NO$ (229.32) | 41 | 37–38; 120/0.001 | 2218 | 1607, 1590, 1571, 1509, 1310, 1249, 1167, 1029 |
| **6n** | 4-Tol | *c*-$C_3H_5$ | Me | $C_{14}H_{15}N$ (197.28) | 70 | 130/0.001 | 2211 | 1591, 1566, 1285, 922, 825 |
| **6o** | 4-Tol | *t*-Bu | Me | $C_{15}H_{19}N$ (213.32) | 55 | 140/0.001 | 2216 | 1593, 1567, 1292, 889, 825 |
| **6p** | 2-Thienyl | *c*-$C_3H_5$ | Me | $C_{11}H_{11}NS$ (189.28) | 69 | 120/0.001 | 2214 | 1580, 1430, 1293, 706 |
| **6q** | 2-Furyl | *c*-$C_3H_5$ | Me | $C_{11}H_{11}NO$ (173.21) | 25[e] | 120/0.001[f] | 2215 | 1657, 1595, 1560, 941, 744 |

[a] All compounds except **6c**,**e**,**f** gave satisfactory elemental analyses.
[b] Kugelrohr distillation.
[c] Film or KBr pellet.
[d] A small amount of the benzamide, derived from unreacted imidoyl chloride during hydrolytic work-up, could not be removed.
[e] Purification by reversed-phase column chromatography [RP-18, elution with a cyclohexane–$Et_2O$–$Et_3N$ (9:1:0.05) mixture].
[f] Partial decomposition of the imine during distillation was observed.

**Table 3** Proypne Iminium Triflates **7** Prepared (Scheme 1) and Selected IR Data

| Product | $R^1$ | $R^2$ | $R^3$ | Molecular formula | Yield[a] (%) | Mp (°C) (solvent) | IR[b] ($cm^{-1}$) $\nu_{C\equiv C}$ | other signals |
|---|---|---|---|---|---|---|---|---|
| **7a** | Ph | *c*-$C_3H_5$ | Me | $C_{15}H_{16}F_3NO_3S$ (347.36) | 95 | 76–78 (EtOAc) | 2202 | 1620, 1264, 1146, 1032, 638 |
| **7b** | Ph | *t*-Bu | Me | $C_{16}H_{20}F_3NO_3S$ (363.40) | 47 | 116–117 ($CH_2Cl_2$–$Et_2O$) | 2219 | 1640, 1264, 1152, 1034, 639 |
| **7l** | $C_6H_4$-4-OMe | *c*-$C_3H_5$ | Me | $C_{16}H_{18}F_3NO_4S$ (377.38) | 88 | 99–100 (EtOAc) | 2191 | 1587, 1256, 1148, 1028, 634 |
| **7n** | 4-Tol | *c*-$C_3H_5$ | Me | $C_{16}H_{18}F_3NSO_3$ (361.38) | 81 | 95–96 (EtOAc) | 2191 | 1600, 1259, 1145, 1028, 634 |
| **7p** | 2-Thienyl | *c*-$C_3H_5$ | Me | $C_{13}H_{14}F_3NS_2O_3$ (353.37) | 84 | 64–65 (EtOAc) | 2207 | 1586, 1259, 1144, 1023, 634 |
| **7q** | 2-Furyl | *c*-$C_3H_5$ | Me | $C_{13}H_{14}F_3NO_4S$ (337.31) | 64 | 109–111 (EtOAc) | 2213 | 1614, 1263, 1143, 1027, 635 |

[a] All salts gave satisfactory elemental analyses.
[b] KBr pellet or neat (ATR measurement).



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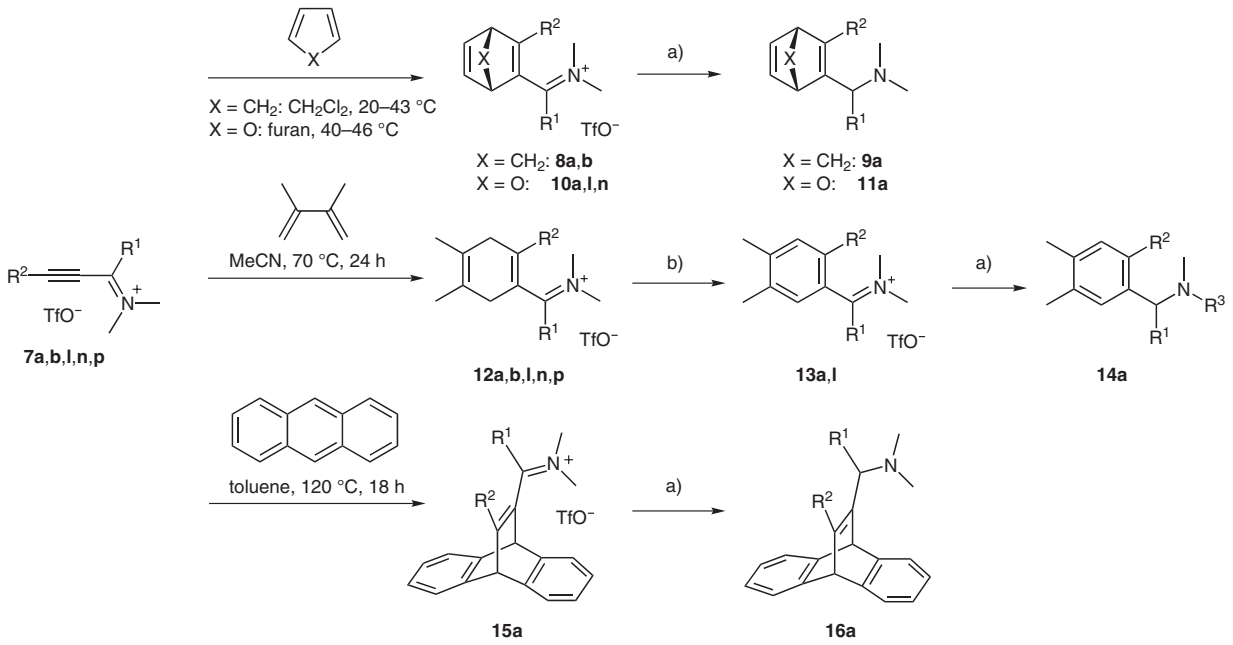


**Scheme 2** *Reagents and conditions*: a) $LiAlH_4$, THF, –20 °C → r.t., 24 h; b) *o*-chloranil, $CH_2Cl_2$, 20 °C, 72 h; or nitrobenzene, 150 °C, 32 h. See Table 5 for $R^1$, $R^2$, further reaction conditions, and yields.

**Table 4** $^1H$ and $^{13}C$ NMR Data of Compounds **6** and **7**

| Product | $^1H$ NMR (400.13 MHz, $CDCl_3$/TMS) δ, *J* (Hz) | $^{13}C\{^1H\}$ NMR (100.61 MHz, $CDCl_3$) δ, *J* (Hz) |
|---|---|---|
| **6a** | 0.89−0.94 (m, 2 H, $CH_2$, *c*-$C_3H_5$), 0.96−0.99 (m, 2 H, $CH_2$, *c*-$C_3H_5$), 1.49−1.58 (m, 1 H, CH, *c*-$C_3H_5$), 3.57 (s, 3 H, $NCH_3$), 7.35−7.39 (m, 3 H, $CH_{Ph}$), 7.94−7.98 (m, 2 H, $CH_{Ph}$) | 0.04 (CH, *c*-$C_3H_5$), 9.43 ($CH_2$, *c*-$C_3H_5$), 43.16 ($NCH_3$), 68.92 (NC*C*≡C), 105.46 (NCC≡*C*), 127.15, 128.02, 130.00, 137.75 ($C_{Ph}$), 152.52 (C=N) |
| **6b** | 1.38 (s, 9 H, *t*-Bu), 3.57 (s, 3 H, $NCH_3$), 7.37−7.40 (m, 3 H), 7.97−7.99 (m, 2 H) | 28.32 [*C*($CH_3$)$_3$], 30.70 [C(*C*$H_3$)$_3$], 43.24 ($NCH_3$), 72.06 (NC*C*≡C), 109.23 (NCC≡*C*), 127.21, 128.10, 130.10, 137.78 ($C_{Ph}$), 152.75 (*C*=N) |
| **6c** | 0.86−0.90 (m, 2 H), 0.92−0.98 (m, 2 H), 1.31 (t, *J* = 7.3 Hz, 3 H), 1.51 (tt, *J* = 5.0, 8.2 Hz, 1 H), 3.79 (q, *J* = 7.3 Hz, 2 H), 7.34−7.38 (m, 3 H), 7.96−7.98 (m, 2 H) | 0.04, 9.34, 15.47, 50.39, 69.03, 104.31, 127.26, 127.99, 129.93, 137.95, 150.47 |
| **6d** | 1.31 (t, *J* = 7.3 Hz, 3 H), 1.37 (s, 9 H), 3.81 (q, *J* = 7.2 Hz, 2 H), 7.36−7.39 (m, 3 H), 7.98−8.00 (m, 2 H) | 15.38, 28.29, 30.68, 50.39, 72.22, 108.79, 127.34, 128.07, 130.00, 138.01, 150.78 |
| **6e** | 0.85−0.94 (m, 2 H), 0.95−1.04 (m, 2 H), 1.52 (tt, *J* = 4.6, 8.5 Hz, 1 H), 4.98 (s, 2 H), 7.24−7.26 (m, 1 H), 7.31−7.45 (m, 7 H), 8.04−8.05 (m, 2 H) | 0.15, 9.49, 59.75, 69.46, 105.06, 126.61, 127.57, 127.92, 128.07, 128.32, 130.26, 137.77, 140.17, 151.58 |
| **6f** | 1.39 (s, 9 H), 5.00 (s, 2 H), 7.22−7.26 (m, 1 H), 7.31−7.36 (m, 2 H), 7.37−7.44 (m, 5 H), 8.04−8.09 (m, 2 H) | |
| **6g** | 0.86−0.90 (m, 2 H), 0.95−1.00 (m, 2 H), 1.23−1.44 (m, 3 H), 1.48−1.58 (m, 3 H), 1.65−1.69 (m, 1 H), 1.74−1.77 (m, 2 H), 1.81−1.86 (m, 2 H), 3.80 (tt, *J* = 4.1, 10.2 Hz, 1 H, CH), 7.34−7.39 (m, 3 H), 7.95−7.97 (m, 2 H) | –0.09, 9.14, 24.61, 25.65, 33.25, 63.91, 69.02, 102.88, 127.18, 127.73, 129.60, 138.02, 148.14 |
| **6h** | 1.35−1.52 (m, 3 H), 1.42 (s, 9 H), 1.58−1.67 (m, 2 H), 1.73−1.76 (m, 1 H), 1.86−1.94 (m, 4 H), 3.88−3.95 (m, 1 H), 7.41−7.42 (m, 3 H), 8.06−8.08 (m, 2 H) | 24.83, 25.78, 28.15, 30.56, 33.28, 64.12, 72.48, 107.42, 127.36, 127.91, 129.77, 138.11, 148.71 |
| **6i** | 0.86−1.00 (m, 4 H), 0.96 (t, *J* = 7.3 Hz, 3 H), 1.44 (sext, *J* = 7.5 Hz, 2 H), 1.48−1.56 (m, 1 H), 1.71 (quint, *J* = 7.3 Hz, 2 H), 3.77 (t, *J* = 7.1 Hz, 2 H), 7.35−7.38 (m, 3 H), 7.95−7.98 (m, 2 H) | 0.09, 9.36, 13.97, 20.74, 32.72, 55.89, 69.29, 104.13, 127.32, 128.03, 129.92, 138.06, 150.55 |
| **6j** | 0.86−0.90 (m, 2 H), 0.94−1.02 (m, 2 H), 1.00 (t, *J* = 7.2 Hz, 3 H), 1.49−1.56 (m, 1 H), 1.75 (sext, *J* = 7.3 Hz, 2 H), 3.73 (t, *J* = 7.0 Hz, 2 H), 7.35−7.38 (m, 3 H), 7.96−7.98 (m, 2 H) | 0.09, 9.38, 12.15, 23.89, 57.94, 69.32, 104.19, 127.32, 128.03, 129.94, 138.06, 150.65 |



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**Table 4** $^{1}H$ and $^{13}C$ NMR Data of Compounds **6** and **7** (continued)

| Product | $^{1}H$ NMR (400.13 MHz, $CDCl_3$/TMS) δ, *J* (Hz) | $^{13}C\{^{1}H\}$ NMR (100.61 MHz, $CDCl_3$) δ, *J* (Hz) |
|---|---|---|
| **6k** | 1.00 (t, *J* = 7.3 Hz, 3 H), 1.37 (s, 9 H), 1.76 (sext, *J* = 7.2 Hz, 2 H), 3.76 (t, *J* = 7.1 Hz, 2 H), 7.36–7.39 (m, 3 H), 7.97–8.02 (m, 2 H) | 12.15, 23.79, 28.28, 30.68, 57.91, 72.47, 108.58, 127.36, 128.05, 129.96, 138.04, 150.90 |
| **6l** | 0.88–0.94 (m, 2 H), 0.95–1.01 (m, 2 H), 1.54 (tt, 1 H, *J* = 5.0, 8.2 Hz, 1 H), 3.57 (s, 3 H), 3.82 (s, 3 H), 6.88 (d, *J* = 8.8 Hz, 2 H), 7.90 (d, *J* = 8.8 Hz, 2 H) | 0.08, 9.44, 43.01, 55.28, 68.98, 105.10, 113.40, 128.71, 130.81, 151.91, 161.25 |
| **6m** | 1.38 (s, 9 H), 3.53 (s, 3 H), 3.83 (s, 3 H), 6.90 (d, *J* = 9.1 Hz, 2 H), 7.93 (d, *J* = 8.8 Hz, 2 H) | 28.32, 30.76, 43.02, 55.28, 72.12, 109.57, 113.43, 128.75, 130.84, 152.07, 161.27 |
| **6n** | 0.88–0.92 (m, 2 H), 0.93–1.00 (m, 2 H), 1.53 (tt, *J* = 5.1, 8.3 Hz, 1 H), 2.36 (s, 3 H), 3.57 (s, 3 H), 7.17, 7.84 (AA′BB′, $^{2}J$ = 7.9 Hz, 4 H) | 0.09, 9.45, 21.29, 43.10, 69.05, 105.19, 127.15, 128.02, 130.00, 137.75, 152.48 |
| **6o** | 1.37 (s, 9 H), 2.37 (s, 3 H), 3.55 (s, 3 H), 7.18, 7.86 (AA′BB′, $^{2}J$ = 7.9 Hz, 4 H) | 21.30, 28.32, 30.74, 43.12, 72.18, 109.66, 127.20, 128.83, 135.29, 140.20, 152.67 |
| **6p** | 0.88–0.92 (m, 2 H), 0.95–1.02 (m, 2 H), 1.52 (tt, *J* = 5.1, 8.3 Hz, 1 H), 3.49 (s, 3 H), 7.02 (dd, *J* = 3.7, 4.9 Hz, 1 H), 7.31 (d, *J* = 5.1 Hz, 1 H), 7.48 (d, *J* = 3.7 Hz, 1 H) | –0.01, 9.43, 42.72, 68.06, 103.83, 127.04, 128.27, 128.87, 144.85, 147.12 |
| **6q** | 0.87–0.93 (m, 2 H), 0.95–1.01 (m, 2 H), 1.52 (tt, *J* = 5.0, 8.3 Hz, 1 H), 3.51 (s, 3 H), 6.43 (dd, *J* = 1.8, 3.3 Hz, 1 H), 6.81 (d, *J* = 3.5 Hz, 1 H), 7.46 (d, *J* = 1.0 Hz, 1 H) | –0.08, 9.34, 42.63, 67.51, 103.21, 111.27, 112.92, 142.89, 144.26, 152.53 |
| **7a** | 1.07–1.11 (m, 2 H, $CH_2$), 1.21–1.26 (m, 2 H, $CH_2$), 1.65–1.71 (m, 1 H, CH), 3.63 (s, 3 H, $NCH_3$), 3.90 (s, 3 H, $NCH_3$), 7.46–7.51 (m, 2 H, $CH_{Ph}$), 7.54–7.58 (m, 1 H, $CH_{Ph}$), 7.62–7.65 (m, 2 H, $CH_{Ph}$) | 1.78 (CH, *c*-$C_3H_5$), 12.35 ($CH_2$, *c*-$C_3H_5$), 45.22 ($NCH_3$), 47.49 ($NCH_3$), 73.05 (NC*C*≡C), 120.75 (q, $^{1}J_{CF}$ = 318.8 Hz, $CF_3$), 128.73, 129.15 ($C_{Ph}$), 130.66 (NCC≡*C*), 131.1, 133.17 ($C_{Ph}$), 163.19 (C=N) |
| **7b** | 1.37 (s, 9 H, *t*-Bu), 3.74 (s, 3 H, $NCH_3$), 4.01 (s, 3 H, $NCH_3$), 7.53–7.57 (m, 2 H, $CH_{Ph}$), 7.61–7.66 (m, 1 H, $CH_{Ph}$), 7.72–7.74 (m, 2 H, $CH_{Ph}$) | 29.17 [C(*C*$H_3$)$_3$], 29.45 [*C*(CH$_3$)$_3$], 45.48 ($NCH_3$), 47.67 ($NCH_3$), 75.48 (NC*C*≡C), 120.84 (q, $^{1}J_{CF}$ = 320.8 Hz, $CF_3$), 128.88, 129.07, 130.91 (NCC≡*C*), 131.15, 133.30, 163.49 (C=N) |
| **7l** | 1.07 (dt, *J* = 7.5, 4.5 Hz, 2 H), 1.21 (td, *J* = 7.8, 4.6 Hz, 2 H), 1.66 (tt, *J* = 8.3, 4.9 Hz, 1 H), 3.67 (s, 3 H), 3.82, 3.83 (2 × s, 3 H each), 6.95–6.98 (m, 2 H), 7.64–7.66 (m, 2 H) | 1.67, 12.15, 45.50, 47.53, 55.78, 72.82, 114.72, 120.81 (q, $^{1}J_{CF}$ = 320.8 Hz), 122.94, 128.55, 132.51, 162.21, 164.17 |
| **7n** | 1.13 (dt, *J* = 7.7, 4.7 Hz, 2 H), 1.26 (td, *J* = 7.7, 4.6 Hz, 2 H), 1.66 (tt, *J* = 4.9, 8.3 Hz, 1 H), 2.42 (s, 3 H), 3.70 (s, 3 H), 3.93 (s, 3 H), 7.33, 7.57 (AA′BB′, $^{3}J$ = 8.1 Hz, 4 H) | 1.85, 12.37, 21.68, 45.42, 47.64, 73.09, 120.85 (q, $^{1}J_{CF}$ = 319.1 Hz), 128.31, 129.33, 129.95, 144.93, 163.29 |
| **7p** | 1.15–1.19 (m, 2 H), 1.26–1.31 (m, 2 H), 1.76 (tt, *J* = 4.8, 8.4 Hz, 1 H), 3.91 (s, 3 H), 3.93 (s, 3 H), 7.34–7.36 (m, 1 H), 8.08–8.12 (m, 2 H) | 1.49, 11.87, 45.82, 48.78, 71.58, 123.96 (q, $^{1}J_{CF}$ = 320.3 Hz), 124.94, 130.12, 133.19, 140.12, 140.38, 152.53 |
| **7q** | 1.15–1.21 (m, 2 H), 1.22–1.29 (m, 2 H), 1.72–1.79 (m, 1 H), 3.89 (s, 3 H), 3.97 (s, 3 H), 6.83 (dd, *J* = 1.5, 3.8 Hz, 1 H), 7.71 (d, *J* = 3.8 Hz, 1 H), 7.99–8.00 (m, 1 H) | 1.35, 11.63, 45.64, 48.61, 68.91, 115.17, 122.64, 131.21, 145.16, 145.64, 152.36 |

**Table 5** [4+2] Cycloaddition Products **8**, **10**, **12**, **13**, **15** Prepared (Scheme 2)[a]

| Product | $R^1$ | $R^2$ | Molecular formula | Reaction conditions | Yield (%) | Mp (°C) (Solvent) |
|---|---|---|---|---|---|---|
| **8a** | Ph | *c*-$C_3H_5$ | $C_{20}H_{22}F_3NO_3S$ (413.46) | $CH_2Cl_2$, 20 °C, 48 h | 92 | 110 (EtOAc–$Et_2O$) |
| **8b** | Ph | *t*-Bu | $C_{21}H_{26}F_3NO_3S$ (429.50) | $CH_2Cl_2$, 43 °C, 48 h | 51 | 95 (EtOAc–$Et_2O$) |
| **10a** | Ph | *c*-$C_3H_5$ | $C_{19}H_{20}F_3NO_4S$ (415.43) | Furan, 46 °C, 39 h | 60 | 113 (dec.) ($CH_2Cl_2$–$Et_2O$) |
| **10l** | $C_6H_4$-4-OMe | *c*-$C_3H_5$ | $C_{20}H_{22}F_3NO_5S$ (445.45) | Furan, 40 °C, 10 d | 68 | 117 (dec.) (EtOAc–$Et_2O$) |
| **10n** | 4-Tol | *c*-$C_3H_5$ | $C_{20}H_{22}F_3NO_4S$ (429.45) | Furan, 40 °C, 10 d | 67 | 114 (dec.) (EtOAc–$Et_2O$) |
| **12a** | Ph | *c*-$C_3H_5$ | $C_{21}H_{26}F_3NO_3S$ (429.50) | MeCN, 70 °C, 24 h | 77 | 157 (EtOAc–$Et_2O$) |
| **12b** | Ph | *t*-Bu | $C_{22}H_{30}F_3NO_3S$ (445.54) | MeCN, 85 °C, 64 h | 82 | 94 (EtOAc–$Et_2O$) |



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**Table 5** [4+2] Cycloaddition Products **8**, **10**, **12**, **13**, **15** Prepared (Scheme 2)[a] (continued)

| Product | $R^1$ | $R^2$ | Molecular formula | Reaction conditions | Yield (%) | Mp (°C) (Solvent) |
|---|---|---|---|---|---|---|
| **12l** | $C_6H_4$-4-OMe | *c*-$C_3H_5$ | $C_{22}H_{28}F_3NO_4S$ (459.52) | MeCN, 75 °C, 94 h | 98 | 124 (EtOAc–$Et_2O$) |
| **12n** | 4-Tol | *c*-$C_3H_5$ | $C_{22}H_{28}F_3NO_3S$ (443.52) | MeCN, 75 °C, 94 h | 80 | 94 (EtOAc–$Et_2O$) |
| **12p** | 2-Thienyl | *c*-$C_3H_5$ | $C_{19}H_{24}F_3NO_3S_2$ (435.52) | MeCN, 80 °C, 72 h | 65 | 93 (EtOAc) |
| **13a** | Ph | *c*-$C_3H_5$ | $C_{21}H_{24}F_3NO_3S$ (427.48) | **12a** in $CH_2Cl_2$, chloranil, 20 °C, 72 h<br>**12a** in nitrobenzene, 150 °C, 32 h | 89<br>90 | 160 ($CH_2Cl_2$–$Et_2O$) |
| **13l** | $C_6H_4$-4-OMe | *c*-$C_3H_5$ | $C_{22}H_{26}F_3NO_4S$ (457.51) | From **7l** and 1,3-diene in MeCN, 75 °C, 94 h, air[b] | 98 | 126 (EtOAc) |
| **15a** | Ph | *c*-$C_3H_5$ | $C_{29}H_{26}F_3NO_3S$ (525.59) | Toluene, 120 °C, 18 h | 97 | 237 (toluene) |

[a] All reactions were carried out under an argon atmosphere (except for the preparation of **13l**) in closed thick-walled Schlenk tubes.
[b] Cyclohexadiene **12l** was not isolated under these conditions.

**Table 6** $^1H$ and $^{13}C$ NMR Data and Selected IR Data for Compounds **8**, **10**, **12**, **13**, **15**

| Product | $^1H$ NMR (400.13 MHz, $CDCl_3$/TMS)[a]<br>δ, *J* (Hz) | $^{13}C\{^1H\}$ NMR (100.6 MHz, $CDCl_3$)[a]<br>δ, *J* (Hz) | IR[b]<br>ν ($cm^{-1}$) |
|---|---|---|---|
| **8a** | 0.84–0.94 (m, 3 H, $CH_2$ cp), 1.02–1.08 (m, 1 H, $CH_2$ cp), 1.27–1.33 (m, 1 H, CH cp), 2.02, 2.06 (AB system, $^2J$ = 7.3 Hz, 2 H, 7-$H_2$), 3.23 (s, 1 H, 4-H), 3.53 (s, 3 H, $NCH_3$), 3.70 (s, 4 H, 1-H, $NCH_3$), 6.59–6.61 (m, 1 H, 5-H), 6.70–6.72 (m, 1 H, 6-H), 7.38–7.41 (m, 2 H), 7.48–7.52 (m, 2 H), 7.54–7.59 (m, 1 H) | 7.63, 8.21 ($CH_2$ cp), 14.81 (CH cp), 45.91, 46.49 ($NCH_3$), 51.60 (C-4), 54.31 (C-1), 67.9 (C-7), 122.40 (q, $^1J_{CF}$ = 319.3 Hz, $CF_3$), 129.28, 129.37, 131.32, 132.89, 140.03 (C-5), 140.56 (C-2), 143.75 (C-6), 178.27 (C=N), 183.75 (C-3) | 1601 (C=N), 1263, 1158, 1035 ($TfO^-$), 638 |
| **8b**[c] | **A**: 1.16 (s, 9 H, *t*-Bu), 1.92 (dt, $^2J$ = 7.3 Hz, $^3J$ < 1 Hz, 1 H, 7-$H^A$), 2.04–2.10 (m, 7-$H^B$, overlap with **B**), 3.70 (br s, 1 H, CH), 3.78 (s, 3 H, $NCH_3$), 3.90 (br s, 1 H, CH), 3.91 (s, 3 H, $NCH_3$), 6.27 (dd, *J* = 2.9, 4.9 Hz, 1 H, =CH), 6.71–6.73 (m, 1 H, =CH), 7.45–7.47 (m, 2 H, CH), 7.54–7.69 (m, 3 H, CH).<br>**B**: 1.09 (s, 9 H, *t*-Bu), 1.98 (dt $^2J$ = 6.6 Hz, $^3J$ < 1 Hz, 1 H, 7-$H^A$), 2.04–2.10 (m, 7-$H^B$, overlap with **A**), 3.52 (s, 3 H, $NCH_3$), 3.78 (s, 4 H, CH, $NCH_3$), 3.84 (br s, 1 H, CH), 6.83 (dd, *J* = 3.4, 4.4 Hz, 1 H, =CH), 7.17 (dd, *J* = 2.9, 4.9 Hz, 1 H, =CH), 7.54–7.69 (m, 3 H), 7.73–7.75 (m, 2 H) | **A**: 27.31 (C*Me*$_3$), 35.11 (*C*Me$_3$), 45.81, 47.93 ($NCH_3$), 55.28, 55.80, 67.65, 140.84, 142.52, 170.32, 185.05.<br>**B**: 27.76 (C*Me*$_3$), 35.09 (*C*Me$_3$), 46.33, 47.45 ($NCH_3$); 54.23, 57.80, 71.81, 141.85, 143.94, 170.42, 187.99.<br>Further signals: 127.96, 129.39 (2 × C), 130.20, 130.34, 131.68, 133.90, 134.09, 137.61, 139.32 | 1611, 1595 (C=N), 1264, 1141, 1031 ($TfO^-$), 634 |
| **10a** | 0.88–1.06 (m, 3 H, $CH_2$ cp), 1.17–1.24 (m, 1 H, $CH_2$ cp), 1.47–1.53 (m, 1 H, CH cp), 3.55 (s, 3 H, $NCH_3$), 3.72 (s, 3 H, $NCH_3$), 5.00 (br s, 1 H, CHO), 5.53 (br s, 1 H, CHO), 6.93 (dd, *J* = 2.0, 5.3 Hz, 1 H, =CH), 6.98 (dd, *J* = 1.6, 5.4 Hz, 1 H, =CH), 7.41–7.43 (m, 2 H), 7.52–7.56 (m, 2 H), 7.58–7.62 (m, 1 H) | 7.48, 9.42 ($CH_2$ cp), 14.28 (CH cp), 46.06, 46.22 ($NCH_3$), 83.31, 85.31 (C-1, C-4), 120.72 (q, $^1J_{CF}$ = 320.5 Hz, $CF_3$), 129.09, 129.55, 130.07, 133.12, 139.49, 140.64, 144.44, 176.34 (C=N), 183.04 (C-3) | 1603, 1573, 1556, 1253, 1223, 1145, 1028, 634 |
| **10l** | 0.86–0.92 (m, 1 H, $CH_2$ cp), 0.95–1.06 (m, 2 H, $CH_2$ cp), 1.16–1.25 (m, 1 H, $CH_2$ cp), 1.40–1.46 (m, 1 H, CH cp), 3.62 (s, 3 H, $NCH_3$), 3.67 (s, 3 H, $NCH_3$), 3.89 (s, 3 H, $OCH_3$), 5.01 (br s, 1 H, CHO), 5.56 (br s, 1 H, CHO), 6.96 (dd, *J* = 2.0, 5.6 Hz, 1 H, =CH), 7.02–7.05 (m, 2 H, $CH_{Ar}$), 7.15 (dd, *J* = 1.5, 5.3 Hz, 1 H, =CH), 7.41–7.45 (m, 2 H, $CH_{Ar}$) | 7.26, 9.29 ($CH_2$ cp), 14.18 (CH cp), 46.14, 46.17 ($NCH_3$), 55.74 ($OCH_3$), 83.26, 85.60, 114.99, 120.82 (q, $^1J_{CF}$ = 320.3 Hz, $CF_3$), 122.25, 132.56, 139.81, 141.41, 144.78, 163.91, 175.65 (C=N), 182.89 (C-3) | 1595, 1258, 1140, 1031, 636 |
| **10n** | 0.89–1.02 (m, 2 H, $CH_2$ cp), 1.04–1.11 (m, 1 H, $CH_2$ cp), 1.22–1.29 (m, 1 H, $CH_2$ cp), 1.54–1.60 (m, 1 H, CH cp), 2.44 (s, 3 H, $CH_3$), 3.60 (s, 3 H, $NCH_3$), 3.75 (s, 3 H, $NCH_3$), 5.02 (br s, 1 H, CHO), 5.50 (br s, 1 H, CHO), 6.94 (dd, *J* = 5.3, 2.0 Hz, 1 H, =CH), 7.05 (dd, *J* = 1.6, 5.4 Hz, 1 H, =CH), 7.32, 7.36 (AA′BB′, $^3J$ = 8.3 Hz, 4 H) | 7.48, 9.41 ($CH_2$ cp), 14.35 (CH cp), 21.71 ($CH_3$), 46.22, 46.34 ($NCH_3$), 83.41, 85.52, 127.28, 129.47, 130.32, 139.50, 140.81, 144.62, 144.70, 176.61 (C=N), 182.86 (C-3) | 1595, 1573, 1556, 1260, 1149, 1030, 635 |
| **12a** | 0.64–0.80 (m, 3 H, $CH_2$ cp), 0.97–1.04 (m, 1 H, $CH_2$ cp), 1.45 (s, 3 H, $CH_3$), 1.47–1.52 (m, 1 H, CH cp), 1.52 (s, 3 H, $CH_3$), 2.20–2.39 (m, 3 H, $CH_2$), 2.64–2.72 (m, 1 H, $CH_2$), 3.68 (s, 3 H, $NCH_3$), 3.78 (s, 3 H, $NCH_3$), 7.46–7.60 (m, 5 H) | 4.64, 4.84 ($CH_2$), 14.70 (CH), 17.37, 17.82 ($CH_3$), 31.08 (C-3), 34.28 (C-6), 45.79 ($NCH_3$), 46.29 ($NCH_3$), 120.62 (q, $^1J_{CF}$ = 319.3 Hz, $CF_3$), 121.07 (C-4), 121.81 (C-5), 124.75 (C-1), 128.53, 129.16, 130.64, 133.01, 141.27 (C-2), 184.22 (C=N) | 1647, 1268, 1152, 1032, 637 |



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**Table 6** $^1$H and $^{13}$C NMR Data and Selected IR Data for Compounds **8**, **10**, **12**, **13**, **15** (continued)

| Product | $^1$H NMR (400.13 MHz, $CDCl_3$/TMS)[a] δ, *J* (Hz) | $^{13}C\{^1H\}$ NMR (100.6 MHz, $CDCl_3$)[a] δ, *J* (Hz) | IR[b] ν ($cm^{-1}$) |
|---|---|---|---|
| **12b** | 1.15 (s, 9 H, *t*-Bu), 1.62 (s, 3 H, $CH_3$), 1.69 (s, 3 H, $CH_3$), 2.39–2.43 (m, 1 H, $CH_2$), 2.83–2.88 (m, 3 H, $CH_2$), 3.85 (s, 3 H, $NCH_3$), 3.90 (s, 3 H, $NCH_3$), 7.59–7.61 (m, 2 H), 7.63–7.66 (m, 1 H), 7.81–7.83 (m, 2 H) | 17.33, 18.15 ($CH_3$), 29.12 [C(*C*$H_3$)$_3$], 35.13, 37.23, 37.39 [*C*($CH_3$)$_3$, C-3, C-6], 45.79, 46.29 ($NCH_3$), 122.16, 123.39, 123.62, 129.52, 130.44, 131.23, 134.56, 146.73, 186.62 (C=N) | 1632, 1257, 1153, 1027, 636 |
| **12l** | 0.71–0.80 (m, 3 H, $CH_2$ cp), 0.95–1.01 (m, 1 H, $CH_2$ cp), 1.38–1.44 (m, 1 H, CH cp), 1.54 (s, 3 H, $CH_3$), 1.61 (s, 3 H, $CH_3$), 2.32–2.48 (m, 3 H, $CH_2$), 2.68–2.75 (m, 1 H, $CH_2$), 3.79 (s, 3 H, $NCH_3$), 3.82 (s, 3 H, $NCH_3$), 3.88 (s, 3 H, $OCH_3$), 7.05 (d, *J* = 8.8 Hz, 2 H), 7.67 (d, *J* = 8.8 Hz, 2 H) | 4.65, 4.96 ($CH_2$ cp), 14.77 (CH cp), 17.62, 18.08 ($CH_3$), 31.59, 35.19 (C-3, C-6), 46.05, 46.46 ($NCH_3$), 55.75 ($OCH_3$), 115.00, 121.36, 121.98, 122.25, 125.35, 132.72, 141.23, 164.17, 183.40 (C=N) | 1600, 1256, 1156, 1025, 633 |
| **12n** | 0.73–0.85 (m, 3 H, $CH_2$ cp), 1.01–1.07 (m, 1 H, $CH_2$ cp), 1.43–1.50 (m, 1 H, CH cp), 1.55 (s, 3 H, $CH_3$), 1.62 (s, 3 H, $CH_3$), 2.25–2.43 (m, 3 H, $CH_{allyl}$), 2.45 (s, 3 H, $CH_3$), 2.71–2.78 (m, 1 H, $CH_{allyl}$), 3.81 (s, 3 H, $NCH_3$), 3.86 (s, 3 H, $NCH_3$), 7.38, 7.57 (AA′BB′ system, $^3J$ = 8.1 Hz, 4 H) | 4.78, 5.08 ($CH_2$ cp), 14.93 (CH cp), 17.65, 18.11, 21.74 ($CH_3$), 31.53, 34.84 (C-3, C-6), 46.09, 46.67 ($NCH_3$), 121.25, 122.26, 125.33, 127.63, 129.47, 130.20, 141.19, 145.00, 184.51 (C=N) | 1642 (w), 1606, 1270, 1256, 1151, 1026, 634 |
| **12p** | 0.63–0.74 (m, 3 H, $CH_2$ cp), 0.85–0.95 (m, 1 H, $CH_2$ cp), 1.30–1.37 (m, 1 H, CH cp), 1.64 (s, 3 H, $CH_3$), 1.66 (s, 3 H, $CH_3$), 2.34–2.47 (m, 2 H, $CH_2$), 2.66, 2.85 (2 × dt, $^2J$ = 21.6 Hz, $^3J$ = 7.1 Hz, 2 H, $CH_2$), 3.82 (s, 3 H, $NCH_3$), 4.05 (s, 3 H, $NCH_3$), 7.41 (t, *J* = 4.4 Hz, 1 H, $CH_{Thie}$), 8.11–8.13 (m, 2 H, $CH_{Thie}$) | 4.69, 4.94 ($CH_2$ cp), 14.71 (CH cp), 17.74, 18.20 ($CH_3$), 31.19, 35.92 (C-3, C-6), 46.15, 46.81 ($NCH_3$), 120.79 (q, $^1J_{CF}$ = 320.5 Hz, $CF_3$), 121.76, 122.01, 125.36, 130.48, 132.37, 140.46, 140.52, 140.94, 173.74 (C=N) | 1647 (w), 1610, 1513, 1405, 1255, 1165, 1146, 1028, 746, 635 |
| **13a** | 0.37–0.44 (m, 1 H, $CH_2$ cp), 0.64–0.74 (m, 2 H, $CH_2$, cp), 0.99–1.06 (m, 1 H, $CH_2$ cp), 1.46–1.53 (m, 1 H, CH cp), 2.23 (s, 3 H, $CH_3$), 2.25 (s, 3 H, $CH_3$), 3.73 (s, 3 H, $NCH_3$), 3.94 (s, 3 H, $NCH_3$), 6.74 (s, 1 H, $CH_{Ph}$), 7.17 (s, 1 H, $CH_{Ph}$), 7.48–7.52 (m, 2 H, $CH_{Ph}$), 7.57–7.61 (m, 3 H, $CH_{Ph}$) | 8.61, 9.31 ($CH_2$ cp), 12.94 (CH cp), 18.95, 19.99 ($CH_3$), 47.03, 47.73 ($NCH_3$), 120.84 (q, $^1J_{CF}$ = 318.6 Hz, $CF_3$), 126.63, 128.57, 129.03, 130.4, 131.21, 132.69, 133.69, 135.34, 139.01, 142.30, 184.71 (C=N) | 1649, 1267, 1152, 1032, 638 |
| **13l** | 0.42–0.49 (m, 1 H, $CH_2$ cp), 0.65–0.73 (m, 2 H, $CH_2$ cp), 0.96–1.04 (m, 1 H, $CH_2$ cp), 1.40–1.47 (m, 1 H, CH cp), 2.24 (s, 3 H, $CH_3$), 2.27 (s, 3 H, $CH_3$), 3.64 (s, 3 H, $CH_3$), 3.88 (s, 3 H, $CH_3$), 3.98 (s, 3 H, $CH_3$), 6.76 (s, 1 H, $CH_{Ph}$), 6.99 (d, *J* = 8.8 Hz, 2 H, $CH_{Ar}$), 7.08 (s, 1 H, $CH_{Ph}$), 7.56 (d, *J* = 8.8 Hz, 2 H, $CH_{Ar}$) | 8.59, 8.91 ($CH_2$ cp), 12.85 (CH cp), 19.00, 20.00 ($CH_3$), 47.00, 47.53 ($NCH_3$), 55.80 ($OCH_3$), 114.60, 120.84 (q, $^1J_{CF}$ = 318.6 Hz, $CF_3$), 124.43, 126.75, 128.99, 131.48, 134.14, 135.28, 139.31, 142.18, 164.47, 184.71 (C=N) | 1623 (w), 1593, 1258, 1181, 1145, 1030, 635 |
| **15a** | 0.89–1.19 (m, 4 H, $CH_2$ cp), 1.44–1.50 (m, 1 H, CH cp), 3.50 (s, 3 H, $NCH_3$), 3.70 (s, 3 H, $NCH_3$), 4.63 (s, 1 H, CH), 5.10 (s, 1 H, CH), 6.90–7.01 (m, 5 H), 7.22–7.25 (m, 3 H), 7.26–7.27 (m, 1 H), 7.38–7.41 (m, 3 H), 7.54–7.58 (m, 1 H) | 6.25 (2 × $CH_2$ cp), 13.77 (CH cp), 46.17, 47.30 ($NCH_3$), 50.62, 53.35 (C-9, C-10), 123.21, 124.04 (q, $^1J_{CF}$ = 318.6 Hz, $CF_3$), 125.29, 125.43, 126.15, 128.1, 129.17, 130.40, 130.45, 131.64, 133.66, 137.71, 166.84, 181.15 (C=N) | 1616, 1258, 1222, 1150, 1030, 639 |

[a] NMR assignments were confirmed by 2D correlation spectra, if necessary; cp = cyclopropyl.
[b] KBr pellet (**8a**,**b**, **15a**) or neat (ATR measurement); w = weak.
[c] Two atropisomers, **A**:**B** = 64:36 ($CDCl_3$, 300 K).

A number of bioactive molecules contain cyclopropyl-substituted arene moieties. For example, recent patent claims mention activities such as reverse transcriptase inhibition,[11] COX-2,[12] and bactericidal properties.[13] Under these aspects, the method developed here may be useful for the construction of more complex targets with potential biological activity.

All reactions involving moisture-sensitive compounds were carried out in rigorously dried glassware under an argon atmosphere. Solvents were dried by established procedures and stored over molecular sieves (4 Å; 3 Å for acetonitrile and ethyl acetate). NMR spectra were recorded on a Bruker DRX 400 spectrometer operating at 400.13 MHz for $^1$H and 100.61 MHz for $^{13}$C. Tetramethylsilane served as internal standard for $^1$H and $CDCl_3$ (δ = 77.0) for $^{13}$C NMR spectroscopic measurements. IR spectra were obtained on a Bruker Vector 22 FT-IR spectrophotometer. Melting points were determined on a Büchi Melting Point B-540 apparatus and are uncorrected. Elemental analyses were carried out with an Elementar Vario EL instrument at the University of Ulm or on a Heraeus CHN–O–Rapid analyzer at the University of Kaiserslautern. The required imidoyl chlorides **5** were prepared according to literature procedures.[14,15]

### *N*-Methyl-3-cyclopropyl-1-phenylprop-2-yn-1-imine (6a); Typical Procedure

To a solution of EtMgBr in THF (30 mL), prepared from magnesium turnings (0.85 g, 35.0 mmol) and bromoethane (4.50 g, 41 mmol), was slowly added at 0 °C cyclopropylacetylene (**4a**; 3.15 g, 31.5 mmol, 70% solution in toluene). The solution was stirred for 30 min at 0 °C, then at r.t., until gas evolution ceased. Copper(I) bro-



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mide dimethyl sulfide complex (0.324 g, 1.6 mmol, 5 mol%) was added in one portion at r.t. and the reaction mixture was stirred for another 5 min. *N*-Methylchloro(phenyl)methanimine (**5a**; 5.38 g, 35 mmol) was slowly added at 0 °C from a dropping funnel. The mixture turned dark red and was stirred overnight at r.t. After dilution with water (100 mL) and extraction with $Et_2O$ (3 × 100 mL), the combined organic layers were washed with sat. aq $NaHCO_3$ solution, dried over $Na_2SO_4$ and concentrated. The residue was purified by Kugelrohr distillation (135 °C/0.03 mbar) to give **6a** as a colorless oil (3.84 g, 67%).

Spectroscopic data are presented in Tables 2 and 4.

Anal. Calcd for $C_{13}H_{13}N$ (183.25): C, 85.21; H, 7.15; N, 7.64. Found: C, 85.12; H, 7.16; N, 7.69.

**Dimethyl-(3-cyclopropyl-1-phenylprop-2-yn-1-ylidene)ammonium Trifluoromethanesulfonate (7a); Typical Procedure for Alkylation of Imines 6 with Methyl Triflate**

To a cooled (–20 °C) solution of methyl triflate (3.50 g, 21.3 mmol) in $Et_2O$ (10 mL) was slowly added a solution of **6a** (2.45 g, 13.3 mmol) in $Et_2O$ (5 mL) from a cooled (–78 °C) dropping funnel. The reaction mixture was stirred at –20 °C for 2 h, during which time an off-white precipitate formed. The liquid phase was pipetted off and the precipitate was triturated twice with $Et_2O$. The light-brown solid was dried in vacuo and recrystallized several times from EtOAc to afford salt **7a** as white crystals (3.23 g, 9.3 mmol, 70%); mp 76–78 °C.

Spectroscopic data are presented in Tables 3 and 4.

Anal. Calcd for $C_{15}H_{16}F_3NO_3S$ (347.36): C, 51.87; H, 4.64; N, 4.03. Found: C, 51.83; H, 4.61; N, 4.05.

Compounds **7b**,**l**,**n**,**p**,**q** were prepared analogously, but the methylations of **6l** and **6n** were carried out at r.t. (Tables 3 and 4).

**Dimethyl-{1-(3-cyclopropylbicyclo[2.2.1]hepta-2,5-dien-2-yl)-1-phenylmethylene}ammonium Trifluoromethanesulfonate (8a)**

The solution of salt **7a** (1.00 g, 2.88 mmol) and freshly distilled cyclopentadiene (0.68 g, 10.33 mmol) in $CH_2Cl_2$ (10 mL) was stirred for 48 h at r.t. The solvent and excess cyclopentadiene were removed in vacuo. The residue was recrystallized from EtOAc, dissolved in $CH_2Cl_2$ and precipitated with $Et_2O$, yielding **8a** as a white powder (1.10 g, 92%); mp 110 °C.

Spectroscopic data are presented in Table 6.

Anal. Calcd for $C_{20}H_{22}F_3NO_3S$ (413.46): C, 58.10; H, 5.36; N, 3.39. Found: C, 58.10; H, 5.36; N, 3.36.

Compound **8b** was prepared analogously (Tables 5 and 6).

**Dimethyl-{1-(3-cyclopropyl-7-oxabicyclo[2.2.1]hepta-2,5-dien-2-yl)-1-phenylmethylene}ammonium Trifluoromethanesulfonate (10a)**

The solution of salt **7a** (2.00 g, 5.76 mmol) in furan (15 mL) was stirred for 39 h at 46 °C. The solvent and excess furan were removed in vacuo. The residue was dissolved in $CH_2Cl_2$ and precipitated with $Et_2O$. The precipitate was washed with $Et_2O$ and EtOAc, yielding **10a** as a slightly yellow powder (1.44 g, 60%); mp 113 °C (dec.).

Spectroscopic data are presented in Table 6.

Anal. Calcd for $C_{19}H_{20}F_3NO_4S$ (415.43): C, 54.93; H, 4.85; N, 3.37. Found: C, 54.92; H, 5.09; N, 3.43.

Compounds **10l**,**n** were prepared analogously (Tables 5 and 6).

**Dimethyl-[1-(cyclopropyl-4,5-dimethylcyclohexa-1,4-dien-1-yl)-1-phenylmethylene]ammonium Trifluoromethanesulfonate (12a)**

The solution of salt **7a** (1.00 g, 2.88 mmol) and 2,3-dimethylbuta-1,3-diene (2.00 g, 24.3 mmol) in MeCN (10 mL) was stirred at 70 °C for 24 h. The solvent and excess diene were removed in vacuo, the residue was dissolved in EtOAc and precipitated with $Et_2O$. The solid was washed twice with $Et_2O$, yielding **12a** as an off-white powder (0.95 g, 77%); mp 157 °C.

Spectroscopic data are presented in Table 6.

Anal. Calcd for $C_{21}H_{26}F_3NO_3S$ (429.50): C, 58.73; H, 6.10; N, 3.26. Found: C, 58.78; H, 6.11; N, 3.26.

Compounds **12b**,**l**,**n**,**p** were prepared analogously (Tables 5 and 6).

**Dimethyl-[1-(2-cyclopropyl-4,5-dimethylphenyl)-1-phenylmethylene]ammonium Trifluoromethanesulfonate (13a)**

(a) The solution of salt **12a** (0.95 g, 2.21 mmol) and *o*-chloranil (0.66 g, 2.44 mmol) in $CH_2Cl_2$ (10 mL) was stirred for 72 h at r.t. The solvent was evaporated, and the residue was dissolved in $CH_2Cl_2$ (5 mL) and precipitated with $Et_2O$. The solvent was pipetted off and the precipitate was washed twice with $Et_2O$, yielding **13a** as a beige powder (0.84 g, 89%); mp 160 °C.

(b) Salt **12a** (0.20 g, 0.46 mmol) was heated in nitrobenzene at 150 °C for 32 h. The solvent was removed in vacuo and the residue was recrystallized from $CH_2Cl_2$–$Et_2O$. Yield of **13a**: 0.18 g (90%).

Spectroscopic data are presented in Table 6.

Anal. Calcd for $C_{21}H_{24}F_3NO_3S$ (427.48): C, 59.0; H, 5.66; N, 3.28. Found: C, 58.90; H, 5.60; N, 3.25.

Compound **13l** was prepared by heating **7l** (0.50 g, 1.32 mmol) and 2,3-dimethylbuta-1,3-diene (0.95 g, 11.56 mmol) in MeCN (4 mL) under aerobic conditions at 75 °C for 6 d. The solvent and excess diene were removed in vacuo. Addition of $Et_2O$ to the oily residue and sonication (30 min) furnished a solid which was recrystallized from EtOAc, yielding **13l** (0.59 g, 98%) as a white powder; mp 126 °C.

Spectroscopic data are presented in Table 6.

***N*,*N*-Dimethyl-1-(16-cyclopropyltetracyclo[6.6.2.0.0]hexadeca-1,3,5,7,9,11,13,15-octaen-15-yl)-1-phenylmethaniminium Trifluoromethanesulfonate (15a)**

The solution of salt **7a** (1.00 g, 2.88 mmol) and anthracene (2.00 g, 11.22 mmol) in toluene (15 mL) was heated in a thick-walled Schlenk tube at 120 °C and stirred for 18 h. A yellow precipitate was formed during the reaction. The hot organic layer was decanted and the solid residue was stirred twice for additional 10 min in toluene (15 mL) at 120 °C (closed Schlenk tube) in order to extract unreacted anthracene. Filtration of the hot mixture furnished **15a** as a beige powder (1.41 g, 93%); mp 237 °C.

Spectroscopic data are presented in Table 6.

Anal. Calcd for $C_{29}H_{26}F_3NO_3S$ (525.59): C, 66.27; H, 4.99; N, 2.67. Found: C, 66.16; H, 4.97; N, 2.67.

**Dimethyl-{1-(3-cyclopropylbicyclo[2.2.1]hepta-2,5-dien-2-yl)-1-phenylmethyl}amine (9a); Typical Procedure for Reduction of Iminium Salts 8, 10, 13, and 15**

To a stirred solution of $LiAlH_4$ in THF (9 mL, 1 mol/L) was slowly added a solution of **8a** (1.00 g, 2.42 mmol) in THF (25 mL) at –20 °C. The mixture was allowed to warm to r.t. over 24 h. $H_2O$ (100 mL) was added and the aqueous phase was extracted with $CH_2Cl_2$ (3 × 150 mL). The combined organic layers were washed with sat. aq NaCl solution (150 mL) and dried ($Na_2SO_4$). The solvent was removed in vacuo to yield **9a** as a light-yellow oil (0.50 g, 78%), which decomposed on attempted Kugelrohr distillation; 61:39 mix-



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ture of diastereomers.

IR (ATR): 1623, 1594, 1576, 1555, 1255, 720 $cm^{-1}$.

$^1H$ NMR ($CDCl_3$; major/minor isomer): δ = 0.48–0.53/0.38–0.45 (m, 1 H, $CH_2$ cp), 0.56–0.68 (m, 2 H, $CH_2$ cp, **A** + **B**), 0.76–0.83 (m, 1 H, $CH_2$ cp, **A** +**B**), 1.43, 1.67/1.71, 1.82 (AB system, $^2J$ = 5.7 Hz, 2 H, 7-$H_2$), 1.88–1.95/1.83–1.87 (m, 1 H, CH cp), 2.11/2.27 (s, 3 H, $NCH_3$), 2.91/2.96 (br s, 1 H, 1-H or 4-H), 3.51/3.54 (br s, 1 H, 1-H or 4-H), 4.10/4.00 (s, 1 H, NCH), 6.52–6.54/6.06–6.08 (m, 1 H, 5-H or 6-H), 6.82–6.84/6.17–6.19 (m, 1 H, 5-H or 6-H), 7.14–7.32 (m, 6 H, $CH_{Ph}$, **B**), 7.22 (m, 4 H, $CH_{Ph}$, **A**), 7.40–7.42 (m, 2 H, $CH_{Ph}$, **A**).

$^{13}C$ NMR ($CDCl_3$): δ = 2.65, 3.17 ($CH_2$ cp, **A** + **B**), 4.37, 4.48 ($CH_2$ cp, **A** + **B**), 9.85, 9.95 (CH cp, **A** + **B**), 44.59, 44.63 ($NCH_3$, **A** + **B**), 48.54, 49.25, 50.38, 51.30 (C-1, C-4, **A** + **B**), 67.33 (C-7, **B**), 70.27, 70.47, 70.76 (C-7, **A** and NCH, **A** + **B**), 126.28–128.12 (6 signals), 138.81, 140.27–148.61 (9 signals).

Anal. Calcd for $C_{19}H_{23}N$ (265.39): C, 85.99; H, 8.74; N, 5.28. Found: C, 85.67; H, 8.72; N, 5.29.

**Dimethyl-{1-(3-cyclopropyl-7-oxabicyclo[2.2.1]hepta-2,5-dien-2-yl)-1-phenylmethyl}amine (11a)**

From salt **10a** (1.13 g, 2.72 mmol) in $CH_2Cl_2$ (10 mL), analogously to the preparation of **9a**. The product mixture obtained after hydrolytic work-up was submitted to column chromatography [silica gel, elution with cyclohexane–EtOAc–$Et_3N$ (2:1:0.03, 1:1:0.02, and 0:1:0.01)], which furnished pure product **11a** in the third fraction and additional product as the major component of the fourth fraction; total yield: ca 130 mg (ca 20%). Light-yellow oil; 60:40 mixture of diastereomers.

IR (ATR): 1452, 992, 872, 701, 649 $cm^{-1}$.

$^1H$ NMR ($CDCl_3$; major/minor isomer): δ = 0.48–0.55/0.41–0.46 (m, 1 H, $CH_2$ cp), 0.66–0.76 (m, 2 H, $CH_2$ cp, **A** + **B**), 0.87–0.96 (m, 1 H, $CH_2$ cp, **A** + **B**), 1.96–2.02/1.80–1.86 (m, 1 H, CH cp), 2.16/2.31 [s, 6 H, $N(CH_3)_2$], 4.08/4.04 (s, 1 H, NCH), 4.83/4.88 (br s, 1 H, CHO), 5.28/5.36 (br s, 1 H, CHO), 6.30 (dd, $J$ = 1.5, 5.3 Hz, 1 H, =CH, **B**), 6.52 (dd, $J$ = 1.8, 5.3 Hz, 1 H, =CH, **B**), 6.86 (dd, $J$ = 1.8, 5.3 Hz, 1 H, =CH, **A**), 7.00 (dd, $J$ = 1.6, 5.4 Hz, 1 H, =CH, **A**), 7.19–7.39 (m, 5 H, **A** + **B**).

$^{13}C$ NMR ($CDCl_3$; major/minor isomer): δ = 2.57/2.38 ($CH_2$ cp), 4.73/4.79 ($CH_2$ cp), 9.23/8.90 (CH cp), 44.25/44.30 [$N(CH_3)_2$], 69.62/66.25 (NCH), 81.79/82.31 (CHO), 84.28/83.16 (CHO), 126.74, 126.89, 127.24, 127.88, 128.21, 128.31, 138.76, 139.32, 140.33, 140.65, 144.04/143.08, 147.88/147.54, 149.83/148.91.

Anal. Calcd for $C_{18}H_{21}NO$ (267.37): C, 80.86; H, 7.92; N, 5.24. Found: C, 80.65; H, 8.01; N, 5.10.

**[α-(2-Cyclopropyl-4,5-dimethylphenyl)benzyl]dimethylamine (14a)**

Prepared from **13a** (0.70 g, 1.60 mmol); colorless oil (0.44 g, 98%).

IR (ATR): 1452, 908, 731, 669 $cm^{-1}$.

$^1H$ NMR ($CDCl_3$): δ = 0.54–0.60 (m, 1 H, $CH_2$ cp), 0.64–0.70 (m, 1 H, $CH_2$ cp), 0.85–0.91 (m, 1 H, $CH_2$ cp), 0.98–1.05 (m, 1 H, $CH_2$ cp), 1.90–2.01 (m, 1 H, CH cp), 2.17 (s, 3 H, $CH_3$), 2.22 (s, 6 H, $NCH_3$), 2.25 (s, 3 H, $CH_3$), 4.69 (s, 1 H, NCH), 6.77 (s, 1 H, $CH_{Ph}$), 7.14–7.18 (m, 1 H, $CH_{Ph}$), 7.23–7.27 (m, 2 H, $CH_{Ph}$), 7.45–7.47 (m, 2 H, $CH_{Ph}$), 7.56 (s, 1 H, $CH_{Ph}$).

$^{13}C$ NMR ($CDCl_3$): δ = 6.95 ($CH_2$ cp), 7.50 ($CH_2$ cp), 13.07 (CH cp), 19.34 ($CH_3$), 19.45 ($CH_3$), 45.0 ($NCH_3$), 71.94 (NCH), 126.65, 128.06, 128.26, 128.32, 134.41, 134.46, 137.23, 140.36, 143.27.

Anal. Calcd for $C_{20}H_{25}N$ (279.42): C, 85.97; H, 9.02; N, 5.01. Found: C, 85.92; H, 8.99; N, 5.06.

**Dimethyl-{1-(16-cyclopropyltetracyclo[6.6.2.0.0]hexadeca-1,3,5,7,9,11,13,15-octaen-15-yl)1-phenylmethyl}amine (16a)**

Prepared from **15a** (0.30 g, 0.57 mmol); white solid (0.15 g, 69%); mp 182–183 °C.

IR (KBr): 1453, 1019, 758, 707 $cm^{-1}$.

$^1H$ NMR ($CDCl_3$): δ = 0.71–0.87 (m, 4 H, $CH_2$ cp), 1.97–2.03 (m, 1 H, CH cp), 2.10 (s, 6 H, $NCH_3$), 4.23 (s, 1 H, CH), 4.43 (s, 1 H, NCH), 5.23 (s, 1 H, CH), 6.62–6.67 (m, 2 H), 6.72–6.78 (m, 1 H), 6.93–6.99 (m, 2 H), 7.02–7.04 (m, 1 H), 7.11–7.18 (m, 1 H), 7.18–7.22 (m, 3 H), 7.34–7.37 (m, 3 H).

$^{13}C$ NMR ($CDCl_3$): δ = 3.77 ($CH_2$ cp), 4.25 ($CH_2$ cp), 10.46 (CH cp), 44.69 ($NCH_3$), 50.13, 50.74, 70.17 (NCH), 121.75–127.98 (11 signals), 140.84, 144.10, 144.17, 145.11, 146.15, 146.60, 146.86.

Anal. Calcd for $C_{28}H_{27}N$ (377.52): C, 89.08; H, 7.21; N, 3.71. Found: C, 88.97; H, 7.12; N, 3.68.

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