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1-(*N*-Acylamino)alkyltriphenylphosphonium salts as synthetic equivalents of *N*-acylimines and new effective α-amidoalkylating agents

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ABSTRACT

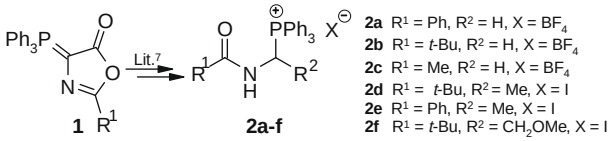
1-(*N*-Acylaminoalkyl)triphenylphosphonium salts **2a–f** on reaction with DBU in MeCN are transformed into 1-(*N*-acylaminoalkyl)amidinium salts **3a–f**. Amidinium salts **3d–f** with a proton at the β-position undergo slow tautomerization into the corresponding enamides **6d–f**. The same 1-(*N*-acylamino)alkyltriphenylphosphonium salts **2d–f** in the presence of Hünig's base are transformed directly into the corresponding enamides. Phosphonium salts **2**, amidinium salts **3**, and enamides **6** react with dialkyl malonates in the presence of DBU to give the corresponding amidoalkylation products. α-Amidoalkylation of dialkyl malonates is not observed in the presence of $(i\text{-Pr})_2$EtN, yet proceeds well under these conditions with more acidic nucleophiles, for example, phthalimide or benzyl mercaptan.

N-Acylimines, which are highly reactive, short-lived intermediates, are used in a wide variety of synthetically useful transformations.[1–3] They are known as strong amidoalkylating agents that are able to react with a range of nucleophiles to give substituted amides,[1] allylic and propargylic primary amines,[1,4] β-aminoketones,[1] or α-amino acid derivatives.[1,5] *N*-Acylimines are also widely used, as both hetero-1,3-dienes and dienophiles in Diels–Alder cycloaddition reactions.[1,6] Most frequently, *N*-acylimines are generated in situ from α-substituted *N*-acylamines via base-catalyzed or thermal elimination.[1] Recently, we described simple and efficient syntheses of 1-(*N*-acylamino)alkyltriphenylphosphonium salts (APS) **2** by hydrolysis and decarboxylation of 4-phosphoranylidene-5(4*H*)-oxazolones **1** or their alkylation products (Scheme 1).[7]

Phosphonium salts **2a–f** are stable, crystalline compounds, which are easy to obtain even on kilogram scale.

In the present Letter, we report our investigations on the complex interactions of 1-(*N*-acylamino)alkyltriphenylphosphonium salts **2** with organic bases (DBU, Et_3N, or $i\text{-Pr}_2$EtN), as well as the amidoalkylating properties of phosphonium salts **2** in the presence of these bases.

N-Acylaminomethyltriphenylphosphonium salts (**2a–c**, $R^2 = H$) reacted immediately when treated with DBU in CD_3CN, as monitored by ^1H NMR. The characteristic signal of the methylene group of the phosphonium salts at δ 5.02–5.27 (dd) was replaced by a singlet in the range δ 4.76–4.99. The ^{13}C NMR spectra of the reaction mixtures also revealed the immediate disappearance of the initial phosphonium salt and formation of free triphenylphosphine and another compound. To identify the structures of the transformation products of phosphonium salts **2a–b,** we repeated these experiments in MeCN and carried out high-resolution mass spectrometry of the reaction mixtures using electrospray ionization. In both cases the formula of the highest mass ion matched the cation of the corresponding *N*-acylaminomethylamidinium salt **3** formed by the amidoalkylation of DBU (Scheme 2, Table 1). Evaporation of MeCN and extraction of triphenylphosphine with toluene gave the pure amidinium salts **3a–b** as thick oils.[8] Attempts to obtain these compounds in crystalline form failed. Further spectroscopic investigations of salts **3a–b** fully confirmed their amidinium structure.[8]



Scheme 1.

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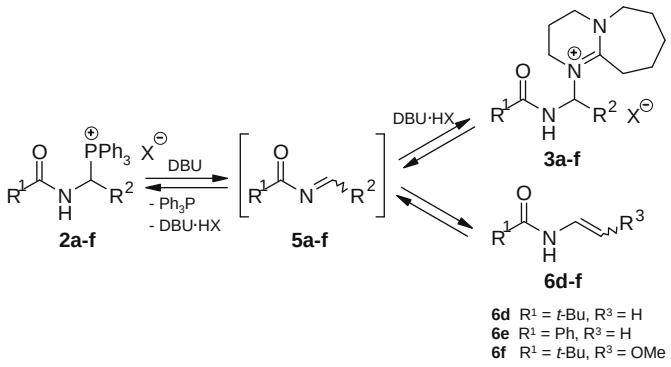
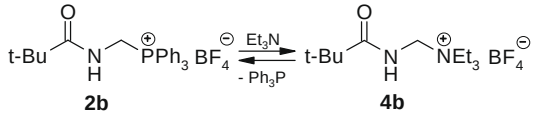


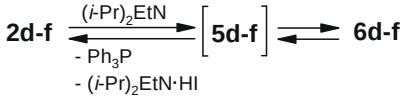
Scheme 2.



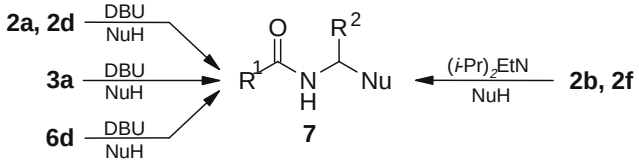
Scheme 3.

A similar result was obtained from a study of the reaction of *N*-acylaminomethyltriphenylphosphonium salts with triethylamine. After addition of triethylamine to a solution of *N*-pivaloylaminomethyltriphenylphosphonium tetrafluoroborate **2b** in CD_3CN, we observed an equilibrium between the starting phosphonium salt and the quaternary ammonium salt **4b**, which was the product of the amidoalkylation of triethylamine (Scheme 3).[9] The conversion of phosphonium salt **2b** into the ammonium salt **4b** increased from 39% at a 1:1.25 molar ratio of phosphonium salt to triethylamine, to 93% at a 1:20 molar ratio of **2b** to Et_3N. Attempts to isolate the ammonium salt **4b** failed, because of the reversibility of this reaction.

In contrast to triethylamine, Hünig's base [$(i\text{-Pr})_2$EtN], which is considered to be a non-nucleophilic base, caused no noticeable changes in the ^{1}H NMR spectra of *N*-acylaminomethyltriphenylphosphonium salts **2a**–**c** in CD_3CN.



Scheme 4.



Scheme 5.

The interaction of bases with α-substituted 1-(*N*-acylamino)alkyltriphenylphosphonium salts **2d–f** ($R^2 \neq H$) differs in many respects from the interactions of *N*-acylaminomethyltriphenylphosphonium salts **2a–c** ($R^2 = H$). The first step of the reaction of 1-(*N*-acylamino)alkyltriphenylphosphonium salts **2d–f** with DBU in CD_3CN was closely analogous to that observed with *N*-acylaminomethyltriphenylphosphonium salts; in spite of steric congestion at the α-carbon, all these phosphonium salts immediately formed the corresponding amidinium salts **3d**–**f**. Amidinium salts **3d** and **3f** were synthesized on a larger scale, isolated and identified as described above for compounds **3a**–**b** (Table 1).[8]

In contrast to the amidinium salts **3a–c**, however, salts **3d**–**f** underwent slow transformation into the corresponding enamides **4d**–**f** in CD_3CN, as monitored by ^{1}H NMR. For example, in the reaction of 1-(*N*-benzoylamino)ethyltriphenylphosphonium iodide **2e** with DBU in CD_3CN at 20 °C at a 1:1.7 molar ratio of **2e** to DBU, after four hours, the **3e**:**6e** molar ratio was 13:87 and after 24 h, the **3e**:**6e** ratio attained a constant value of 6:94. Similar results were obtained with phosphonium iodides **2d** and **2f**. The rate of this transformation rose with increased phosphonium salt:DBU molar ratio. The experiments with salts **2d** and **2e** were repeated on a larger scale in MeCN in order to isolate the corresponding enamides in pure form, however, we were successful only in the case of enamide **6d** (Table 2, Procedure A).[10] We were unable to isolate

Table 1
Transformation of phosphonium salts **2** into amidinium salts **3**[8]

	APS **2**			Molar ratio of	Amidinium salt **3**		HR-ESI-MS (*m*/*z*)		
	R^1	R^2	X	APS **2** to DBU		Yield (%)	Formula[a]	Calcd	Found
2a	Ph	H	BF_4	1:1	**3a**	82	$C_{17}H_{24}N_3O$	286.1913	286.1908
2b	*t*-Bu	H	BF_4	1:1	**3b**	93	$C_{15}H_{28}N_3O$	266.2227	266.2230
2d	*t*-Bu	Me	I	1:1.25	**3d**	75	$C_{16}H_{30}N_3O$	280.2383	280.2385
2f	*t*-Bu	CH_2OMe	I	1:1.25	**3f**	77	$C_{17}H_{32}N_3O_2$	310.2489	310.2491

[a] Formula of the amidinium cation.

Table 2
Transformation of phosphonium salts 2 into enamides **6**

APS **2**				Reaction conditions			Enamide **6**			
Salt	R^1	R^2	X	Procedure[10]	Temp. (°C)	Time		R^3	Yield (%)	Mp[a] (°C)
2d	*t*-Bu	Me	I	A	20	6 d	**6d**	H	48	92–93[b]
2f	*t*-Bu	CH_2OMe	I	B	60	10 h	**6f**	OMe	81[c]	107–108[d]

[a] After recrystallization from toluene.
[b] Lit. mp 99–101 °C (from hexane).[11]
[c] A mixture of *Z* and *E* isomers in a molar ratio of 66:34.
[d] Mp of the *E* isomer recrystallized from toluene.

Table 3
α-(*N*-Acylamino)alkyltriphenylphosphonium salts and their derivatives as amidoalkylating agents[13]

Amidoalkylating agent					NuH	Reaction conditions				Reaction product **7**		
	R^1	R^2	R^3	X		Procedure[13]	Base	Temp. (°C)	Time		Yield (%)	Mp (°C)
2a	Ph	H	—	BF_4	$CH_2(CO_2Me)_2$	C	DBU	60	1.5 h	**7a**	64	94–95
3a	Ph	H	—	BF_4	$CH_2(CO_2Me)_2$	C	DBU	60	1.5 h	**7a**	60	
2b	*t*-Bu	H	—	BF_4	Benzyl mercaptan	D	$(i\text{-Pr})_2$EtN	20	4 d	**7b**	92	45.5–46
2d	*t*-Bu	Me	—	I	$CH_2(CO_2Et)_2$	C	DBU	60	1.5 h	**7d**	61	oil
6d	*t*-Bu	—	H	—	$CH_2(CO_2Et)_2$	C	DBU	60	1 h	**7d**	82	oil
2f	*t*-Bu	CH_2OMe	—	I	Phthalimide	D	$(i\text{-Pr})_2$EtN	60	10.5 h	**7f**	76	122–123

the enamide **6e**, probably due to its polymerization during column chromatography.

Phosphonium salts **2d–f** in CD_3CN in the presence of Hünig's base at 20 °C underwent direct transformation into the corresponding enamides **6d–f**, as monitored by ^{1}H NMR (Scheme 4). The reaction of phosphonium salt **2f** with Hünig's base on large scale in MeCN at 60 °C, gave a mixture of *Z* and *E* isomers of enamide **6f** in a molar ratio of 66:34 and in a yield of 81% (Table 2, Procedure B).[10]

The findings described above can be rationalized assuming that 1-(*N*-acylamino)alkyltriphenylphosphonium salts **2**, both α-substituted and α-unsubstituted, are transformed under the influence of DBU into the corresponding *N*-acylimines **5** as the primary reaction products, which in turn react with DBU to give amidinium salts **3**. Amidinium salts **3d–f** with a proton at the β-position undergo slow transformation directly, or more probably via *N*-acylimines, into the corresponding enamides **6d–f**. Tautomerization of *N*-acylimines to the corresponding enamides is a well-known phenomenon.[12]

This conclusion was confirmed by the observation that both types of *N*-acylaminoalkyltriphenylphosphonium salts **2** (R^2 = H and $R^2 \neq$ H) reacted smoothly with dialkyl malonates in the presence of DBU under the influence of microwave irradiation at 60 °C to give the expected α-amidoalkylation product (Scheme 5, Table 3, Procedure C).[13] The isolated and purified amidinium salt **3a** also reacted easily with diethyl malonate under the same conditions to give the corresponding amidoalkylation product. Unexpectedly, *N*-vinylpivaloamide **6d** also reacted with diethyl malonate under these conditions to give the amidoalkylation product **7d**, in a better yield than from the corresponding phosphonium salt **2d** (Scheme 5, Procedure C, Table 3).[13] It is well known that enamides can act as α-amidoalkylation reagents, although usually following C-protonation to an acyliminium cation.[14] The results of the two latter experiments can be explained assuming that phosphonium salts **2**, amidinium salts **3**, enamides **6**, and *N*-acylimines **5** remain in equilibrium under the applied reaction conditions.

1-(*N*-Acylamino)alkyltriphenylphosphonium salts **2** did not react with dialkyl malonates in the presence of Hünig's base in MeCN. However, the amidoalkylation reaction proceeded smoothly under these conditions with more acidic nucleophiles, for example, phthalimide or benzyl mercaptan (Scheme 5, Procedure D, Table 3).[13] Taking these results into account, and keeping in mind that Hünig's base transforms phosphonium salts **2d–f** into the corresponding enamides, one can speculate that Hünig's base also generates *N*-acylimines from 1-(*N*-acylamino)alkyltriphenylphosphonium salts, however, in this case, the reaction equilibrium is shifted toward phosphonium salts **2a–c** or enamides **6d–f**.

In conclusion, 1-(*N*-acylamino)alkyltriphenylphosphonium salts **2** display strong amidoalkylating properties in the presence of organic bases such as DBU and Hünig's base. It can be assumed that deprotonation and elimination of triphenylphosphine from phosphonium salts **2** under the influence of the base lead to the corresponding highly reactive *N*-acylimines, which are responsible for the amidoalkylating properties of this reaction system. In reactions carried out in the presence of DBU, unstable *N*-acylimines remain in equilibrium with phosphonium salts **2**, the 1-(*N*-acylamino)alkylamidinium salt **3** derived from DBU and, in the case of phosphonium salts, with a proton at the β-position, with the corresponding enamides **6**. It seems that non-nucleophilic Hünig's base also generates *N*-acylimines from 1-(*N*-acylamino)alkyltriphenylphosphonium salts, however, in this case, the reaction equilibrium is shifted toward phosphonium salts **2a–c** or enamides **6d–f**.

Acknowledgment

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8. *Experimental procedure for compounds* **3**: To a suspension of APS **2** (1 mmol) in CH_3CN (11 cm^3), DBU (0.15 cm^3, 1 mmol for **2a–b** or 0.19 cm^3, 1.25 mmol for **2d** and **2f**) was added at 20 °C. After 10 min the solvent was evaporated under reduced pressure. The residue was extracted with toluene at room temperature. After evaporation of the solvent and drying under reduced pressure, the amidinium salts **3** were obtained in the yields given in Table 1.
Compound **3a**: oil; IR (CH_3CN, cm^{-1}): 3380br, 3212br, 1668s, 1652s, 1620vs, 1532s; ^{1}H NMR (600 MHz, CD_3CN): δ 7.94 (br s, 1H), 7.85–7.49 (m, 5H), 5.01 (d, *J* = 6.0 Hz, 2H), 3.64–3.60 (m, 4H), 3.46–3.44 (m, 2H), 3.05–3.04 (m, 2H), 2.04–2.01 (m, 2H), 1.75–1.73 (m, 4H), 1.68–1.66 (m, 2H); ^{13}C NMR (150 MHz, CD_3CN): δ 168.65, 168.62, 134.24, 133.21, 129.69, 128.35, 58.51, 55.88, 50.19, 47.50, 29.16, 29.00, 26.40, 23.43, 20.56.
Compound **3b**: oil; IR (CH_3CN, cm^{-1}): 3400br, 3220br, 1672s, 1620vs, 1520s; ^{1}H NMR (300 MHz, CD_3CN): δ 7.24 (br s, 1H), 4.77 (d, *J* = 6.0 Hz, 2H), 3.61–3.58 (m, 2H), 3.53–3.49 (m, 2H), 3.46–3.42 (m, 2H), 2.98–2.94 (m, 2H), 2.02–1.93 (m, 2H), 1.79–1.65 (m, 6H), 1.15 (s, 9H); ^{13}C NMR (75.5 MHz, CD_3CN): δ 180.18, 168.42, 58.17, 55.69, 50.07, 47.00, 39.33, 28.94, 28.90, 27.46, 26.37, 23.49, 20.53.
Compound **3d**: IR (CH_3CN, cm^{-1}): 3376br, 3196br, 1676s, 1652s, 1612vs, 1508s; ^{1}H NMR (600 MHz, CD_3CN): δ 7.23 (br s, 1H), 5.86 (dq, J_1 = 6.7 Hz, J_2 = 6.7 Hz 1H), 3.68–3.64 (m, 1H), 3.57–3.53 (m, 1H), 3.44–3.39 (m, 3H), 3.34–3.28 (m, 1H), 3.01–2.96 (m, 2H), 2.05–1.98 (m, 1H), 1.91–1.86 (m, 1H), 1.83–1.70 (m, 6H), 1.49 (d, *J* = 7.2 Hz 3H), 1.18 (s, 9H); ^{13}C NMR (150 MHz, CD_3CN): δ 179.77, 167.50, 63.82, 55.36, 50.31, 39.91, 39.42, 28.83, 27.63, 26.65, 23.15, 20.91, 18.75.
Compound **3f**: oil; 3368br, 3236br, 1676s, 1652s, 1612vs, 1520s; ^{1}H NMR (300 MHz, CD_3CN): δ 7.47 (br d, *J* = 6.9 Hz, 1H), 5.93 (ddd, *J* = 8.4 Hz, *J* = 7.2 Hz, *J* = 4.8 Hz, 1H), 3.88 (dd, *J* = 10.2 Hz, *J* = 8.4 Hz, 1H), 3.65–3.62 (m, 2H), 3.58 (dd, *J* = 10.5 Hz, *J* = 4.8 Hz, 1H), 3.48–3.41 (m, 4H), 3.36 (s, 3H), 3.12–2.94 (m, 2H), 1.95–1.68 (m, 8H), 1.19 (s, 9H); ^{13}C NMR (75.5 MHz, CD_3CN): δ 179.89, 168.37, 70.34, 65.99, 59.42, 55.27, 50.21, 40.45, 39.42, 28.76, 28.50, 27.53, 26.35, 22.98, 20.61.
9. To a solution of APS **2b** (1 μmol) in CD_3CN (0.8 cm^3), Et_3N (1.25 μmol or 2 μmol or 20 μmol) was added. The progress of the reaction was monitored by ^{1}H NMR spectroscopy.
N-pivaloylaminomethyltriethylammonium tetrafluoroborate **4b**: ^{1}H NMR (300 MHz, CD_3CN): δ 7.19 (br s, 1H), 4.52 (d, *J* = 7.2 Hz, 2H), 3.11 (q, *J* = 7.2 Hz, 6H), 1.291 (t, *J* = 7.2 Hz, 3H), 1.286 (t, *J* = 7.2 Hz, 3H), 1.280 (t, *J* = 7.2 Hz, 3H), 1.22 (s, 9H); ^{13}C NMR (75 MHz, CD_3CN): δ 181.16, 61.22, 51.53, 39.81, 27.25, 7.86.
10. *Procedure A:* To a suspension of APS **2d** (1 mmol) in CH_3CN (11 cm^3), DBU (0.19 cm^3, 1.25 mmol) was added. The reaction mixture was left for 6 d at rt

and then the solvent was evaporated under reduced pressure. The residue was purified by column chromatography (silica gel, 1:2 EtOAc/toluene) to afford **6d** in 48% yield.

Compound **6d**[11]: white powder, ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.30 (br s, 1H), 7.00 (ddd, J = 15.8 Hz, J = 10.8 Hz, J = 8.4 Hz, 1H), 4.62 (d, J = 15.6 Hz, 1H), 4.42 (d, J = 8.7 Hz, 1H), 1.23 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 175.72, 129.12, 94.92, 38.68, 27.35.

Procedure B: To a suspension of APS **2f** (1 mmol) in CH_3CN (4 cm^3), (i-Pr)$_2$EtN (0.26 cm^3, 1.5 mmol) was added. The reaction mixture was heated in a sealed reaction vial at 60 °C for 10 h. The solvent was evaporated under reduced pressure and the residue was purified by column chromatography (silica gel, 1:2 EtOAc/toluene) to give two isomers of the enamide **6f**. *Z* isomer: colorless oil, 53%, IR (CH_2Cl_2, cm^{-1}): 3456 m, 1664vs, 1492vs; ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.32 (br s, 1H), 6.17 (dd, J = 10.2 Hz, J = 4.8 Hz, 1H), 5.58 (d, J = 4.8 Hz, 1H), 3.65 (s, 3H), 1.23 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 174.73, 133.22, 104.15, 59.96, 38.79, 27.46; HR-EI-MS m/z for $C_8H_{15}NO_2$ [M$^+$]: calcd 157.1103; found 157.1096. *E* isomer: colorless needles; 28%; IR (CH_2Cl_2, cm^{-1}): 3456 m, 1664vs, 1500vs; ^{1}H NMR (600 MHz, $CDCl_3$): δ 6.82 (br s, 1H), 6.66 (d, J = 12 Hz, 1H), 6.39 (dd, J = 12 Hz, J = 9 Hz, 1H), 3.55 (s, 3H), 1.22 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 175.72, 139.32, 104.94, 56.77, 38.72, 27.50; HR-EI-MS m/z for $C_8H_{15}NO_2$ [M$^+$]: calcd 157.1103; found 157.1097.

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13. *Procedure C:* A solution of phosphonium salt (**2a** or **2d**), or amidinium salt **3a**, or enamide **6d** (1 mmol), dimethyl malonate (8 mmol) or diethyl malonate (6 mmol) and DBU (2 mmol) in CH_3CN (8 cm^3) was irradiated in a sealed reaction vial at a power of 10–12 W in a microwave reactor (CEM Matthews) at 60 °C for the time given in Table 3. The solvent was evaporated under reduced pressure and the product was isolated by column chromatography (silica gel, 1:5 EtOAc/toluene) to give compound **7a** or **7d**. Product **7a** was recrystallized from toluene.

Compound **7a**: IR (CH_2Cl_2, cm^{-1}): 3455 m, 1748vs, 1736vs, 1664vs, 1520vs; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.76–7.73 (m, 2H), 7.54–7.40 (m, 3H), 6.86 (br s, 1H), 3.97 (dd, J = 6.3 Hz, J = 6.0 Hz, 2H), 3.83 (t, J = 6.3 Hz, 1H), 3.78 (s, 6H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 168.69, 167.45, 133.99, 131.67, 128.58, 126.93, 52.85, 50.91, 38.26; Anal. Calcd for $C_{13}H_{15}NO_5$: C, 58.86; H, 5.70; N, 5.28. Found: C, 58.91; H, 5.62; N, 5.29.

Compound **7d**: IR (CH_2Cl_2, cm^{-1}): 3444 m, 1744vs, 1728vs, 1660vs, 1512vs; ^{1}H NMR (600 MHz, $CDCl_3$): δ 6.81 (br d, J = 8.4 Hz, 1H), 4.68 (ddq, J = 4.2 Hz, J = 6.8 Hz, J = 8.4 Hz, 1H), 4.26 (dq, J = 10.8 Hz, J = 7.2 Hz, 1H), 4.23 (dq, J = 11.4 Hz, J = 7.2 Hz, 1H), 4.18 (dq, J = 10.2 Hz, J = 7.2 Hz, 1H), 4.16 (dq, J = 10.2 Hz, J = 7.2 Hz, 1H), 3.57 (d, J = 4.2 Hz, 1H), 1.30 (dd, J = 7.2 Hz, J = 7.2 Hz, 3H), 1.26 (dd, J = 7.2 Hz, J = 7.2 Hz, 3H), 1.25 (d, J = 7.2 Hz, 3H), 1.17 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 177.52, 168.62, 167.67, 61.65, 61.50, 55.55, 44.15, 38.56, 27.36, 18.96, 13.98; HR-ESI-MS m/z for $C_{14}H_{25}NO_5Na$ [M+Na$^+$]: calcd 310.1625; found 310.1610.

Procedure D: To a stirred suspension of APS **2b** or **2f** (1 mmol) in CH_3CN (4 cm^3), benzyl mercaptan (2 mmol) or phthalimide (1.1 mmol) and (i-Pr)$_2$EtN (1.5 mmol) were added. The reaction mixture was left at rt or was heated at 60 °C for the time given in Table 3. The solvent was evaporated under reduced pressure and the product was isolated by column chromatography (silica gel, 1:5 EtOAc/toluene) to give compound **7b** or **7f**. The solid products **7b** and **7f** were recrystallized by dissolving in toluene and precipitated on addition of hexane.

Compound **7b**: IR (CH_2Cl_2, cm^{-1}): 3456 m, 1664vs, 1512vs, 1500vs; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.38–7.23 (m, 5H), 5.69 (br s, 1H), 4.37 (d, J = 5.7 Hz, 2H), 3.79 (s, 2H), 1.09 (s, 9H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 178.08, 138.89, 128.76, 128.75, 127.20, 41.60, 38.58, 36.17, 27.25; Anal. Calcd for $C_{13}H_{19}NOS$: C, 65.78; H, 8.07; N, 5.90. Found: C, 65.94; H, 8.15; N, 5.92.

Compound **7f**: IR (CH_2Cl_2, cm^{-1}): 3448 m, 1776s, 1720vs, 1676vs, 1504vs; ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.84 (dd, J = 5.4 Hz, J = 3.0 Hz, 2H), 7.73 (dd, J = 5.3 Hz, J = 3.0 Hz, 2H), 6.98 (br d, J = 9.6 Hz, 1H), 6.43 (ddd, J = 9.0 Hz, J = 7.8 Hz, J = 5.4 Hz, 1H), 3.80 (dd, J = 10.8 Hz, J = 7.8 Hz, 1H), 3.67 (dd, J = 10.8 Hz, J = 5.7 Hz, 1H), 3.39 (s, 3H), 1.20 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$): δ 177.86, 167.73, 134.17, 131.74, 123.51, 71.31, 58.96, 55.20, 38.88, 27.31; HR-ESI-MS m/z for $C_{16}H_{20}N_2O_4Na$ [M+Na$^+$]: calcd 327.1315, found: 327.1330.

14. Lukyanov, S. M. In *The Chemistry of Enamines, Chemistry of Functional Groups*; Rappoport, Z., Ed.; Wiley, 1994; p 1441.