Ketenes and mesoions. Interconversion of mesoionic pyridopyrimidinium olates and pyridopyrimidinones. (2-Pyridyl)iminopropadienone. Part 2†[1]

Heidi Gade Andersen, Ullrich Mitschke and Curt Wentrup*

Department of Chemistry, The University of Queensland, Brisbane, Qld 4072, Australia.
E-mail: wentrup@chemistry.uq.edu.au

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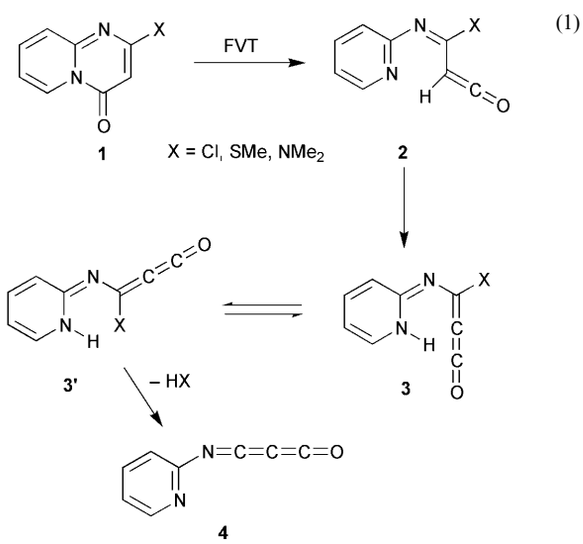
Mesoionic pyrido[1,2-*a*]pyrimidinium olates **9** undergo rearrangement to the lower-energy pyridopyrimidinones **7** in solution at ordinary temperatures ($t_{1/2} \approx 51$ min at 75 °C), formally *via* the higher-energy ketene valence isomers **11**. These ketenes are not directly detectable, and DFT calculations at the B3LYP/6-31G* level indicate that the rearrangement may be concerted *via* the ketenoid transition state **11TS**, although the ketene conformer **11M** is locally stable. FVT of the pyridopyrimidinones **7** is a method of synthesis of (2-pyridyl)iminopropadienone **4**, a reaction thought to proceed *via* ring opening to the same ketenes **11** followed by elimination of the 2-(methylamino)pyridine **8**. Recombination of **8** and **4** leads to mesoions **9** together with minor amounts of the isomers **10**.

Introduction

(2-Pyridyl)iminopropadienone **4** is obtained by flash vacuum thermolytic elimination of HX from pyridopyrimidinones **1**, most efficiently when X = NMe_2.[1] The mechanism is not a straightforward 1,2-elimination but is thought instead to involve ring opening to an imidoylketene **2**, proton transfer to the pyridine-N giving **3**, and 1,4-elimination to **4** [eqn. (1)].[1]



(1)

Cumulene **4** has been characterised by low temperature IR spectroscopy and by its chemical reactions. It reacts with nucleophiles, first on the ketenic carbon atom to produce an acylketenimine, then on the keteniminic carbon atom to produce a malonic imide derivative. Other aryliminopropadienones undergo similar reactions.[2] Work in progress demonstrates a very rich chemistry of iminopropadienones generally, *e.g.* with formation of 5- to 9-membered cyclic compounds by addition of dinucleophiles.[3] Here we report the preparation of mesoionic pyridopyrimidinium olates **9** and **10** from **4** and 2-(methylamino)pyridines **6** as well as the rearrangement of **9** to **7**.

Results and discussion

The pyridylamino-substituted pyridopyrimidinones **7** were prepared by nucleophilic displacement of chloride from compound **5** (Scheme 1). An unsubstituted analog has been obtained by this method previously.[4] Flash vacuum thermolysis (FVT) of **7** with matrix isolation of the products in Ar at 7–10 K afforded (2-pyridyl)iminopropadienone **4**, whose IR spectrum was identical with the previously reported one[1] (main band at 2249–2250 cm^{-1}). The IR spectrum was also in excellent agreement with a DFT calculated spectrum (B3LYP/6-31G**). The spectra are shown in the supplementary data. The formation of **4** started at an FVT temperature of *ca.* 700 °C and was complete at *ca.* 860 °C.

Similar experiments were performed with deposition of the FVT products at 50 K, *i.e.* without Ar. The main IR band of **4** appeared at 2239 cm^{-1} under these conditions. Subsequent warm-up demonstrated that **4** was stable to *ca.* 180 K. The experiments reported below reveal that **4** disappeared by reaction with the co-condensed amines **8** to generate the mesoionic compounds **9** and **10**.

Preparative FVT of **7** afforded the mesoionic pyridopyrimidinium olates **9** in yields of 50–70%. NMR spectroscopy revealed the presence of a second isomer in inferior yields, 10–25%, identified as **10**. Normally, isomers **9** and **10** elute together on chromatography, but it is possible to isolate pure samples of **10** by selective destruction of mesoions **9**, which isomerise to the starting materials **7** on gentle heating in solution (see below). Since compounds **10** are much more polar than **7**, separation now becomes easy.

Mesoions **9** correspond to the "normal" mode of addition of aminopyridines to iminopropadienones, *viz.* the more nucleophilic pyridine-N adding to the more reactive ketene-type C=O group of **4**, followed by slower addition of the amine-N to the less reactive ketenimine-type C=N bond of **4**. We have discovered several examples of this general mode of addition.[2,3,5] The formation of **10** then corresponds to the opposite mode of

† Tables and a figure of experimental and calculated (B3LYP/6-31G*) IR spectra of **4** and **8**, kinetic data for the rearrangement of **9** to **7**, and cartesian coordinates, thermochemical data and IR spectra for all calculated structures are available as supplementary data. For direct electronic access see http://www.rsc.org/suppdata/p2/b0/b007298m/

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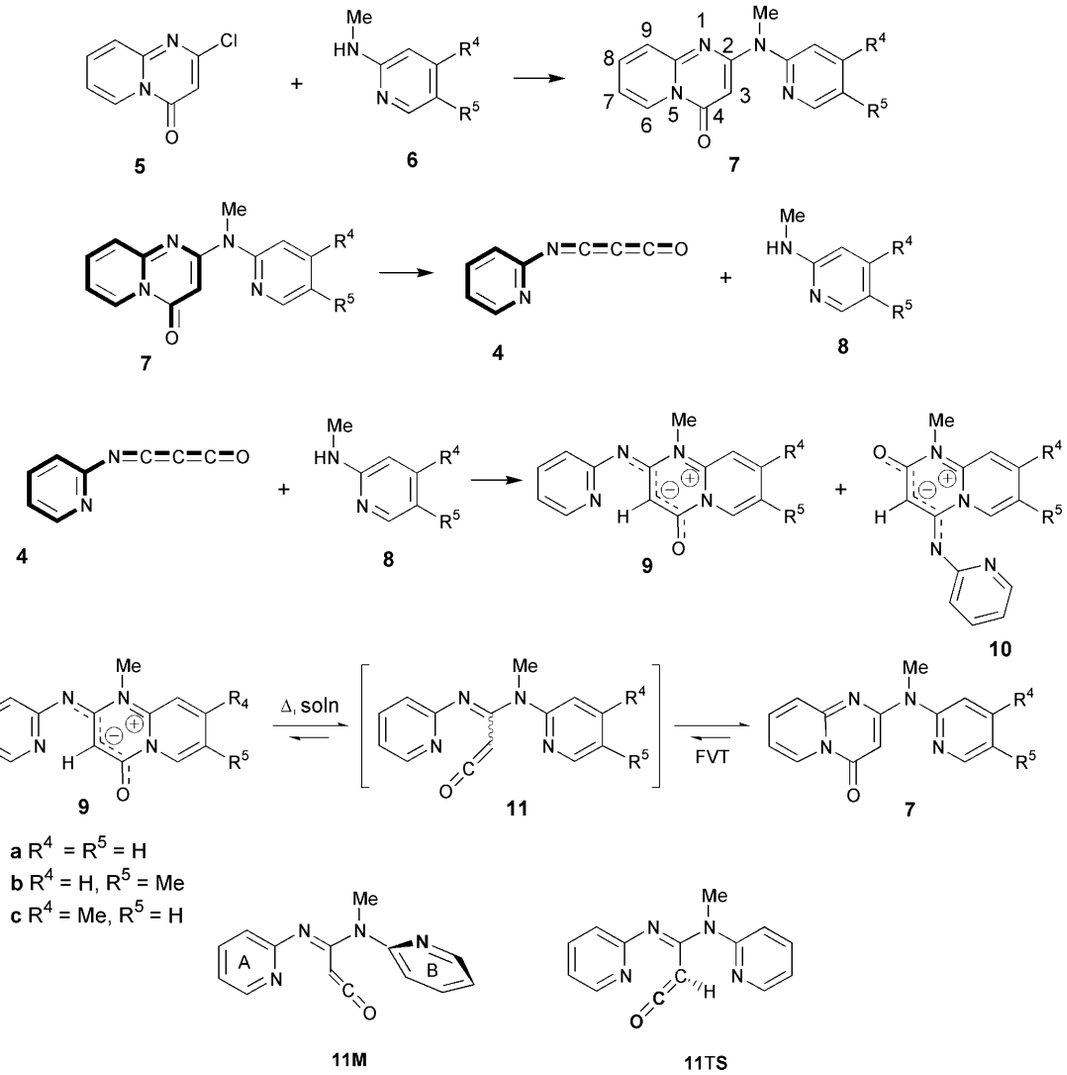
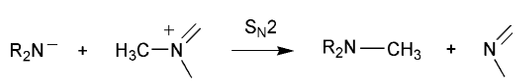


Scheme 1

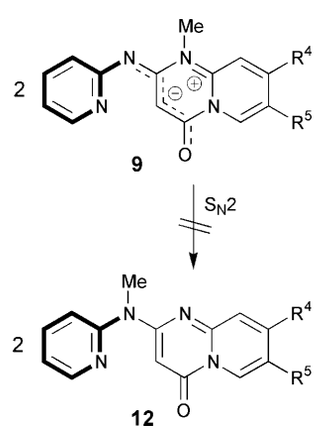
addition, with the amine-N first attacking the ketene C=O group. The partitioning between these two modes can be modulated by substituents on the pyridine ring. Thus, a ring-methyl group *para* to the amino group enhances its nucleophilicity and increases the yield of the "wrong" isomer, **10**. The structures of **9** and **10** follow from the NMR data, including a ^{13}C-DEPT and a 2D HSQC ^{1}H–^{13}C correlation. The high field shifts of H-3 (5–6 ppm) and C-3 (75–81 ppm) in **9** and **10** are particularly characteristic of mesoionic pyridopyrimidinium olates and related compounds having a partial negative charge at C-3.[5,6]

Compounds **9** are obtained as crystalline solids (together with **10**) but are only metastable at room temperature. Compound **9a** rearranges to the starting material **7a**, slowly at room temperature, and rapidly at 100 °C (quantitatively in 15 min). This apparent 1,3-shift of a methyl group could be either a bimolecular (second order) S_N2 type process [see eqns. (2) and



(2)

(3)] or an intramolecular (first order) reaction *via* ring opening to the ketene intermediate **11** (Scheme 1). Monitoring of the kinetics of the rearrangement of **7a** by ^{1}H NMR spectroscopy proved that the reaction is first order, *i.e.* it is not an S_N2 process [eqn. (3)] but an intramolecular rearrangement. Product studies with **9b** and **9c** demonstrated that the pyridine rings are interchanged (see Scheme 1) which is incompatible with the S_N2 reaction [eqn. (3)].



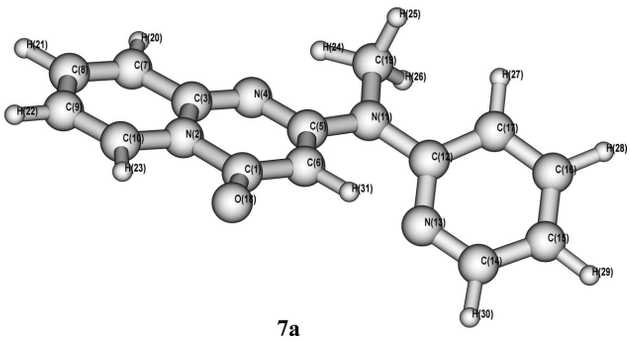
(3)

The results therefore indicate that mesoions **9** are metastable with respect to the isomeric non-mesoionic pyridopyrimidinone **7**, to which they rearrange easily *via* ring opening to the transient ketene **11**. However, as shown in the following section, ketene **11** may only be a transition state in the concerted isomerisation of **9** to **7**.

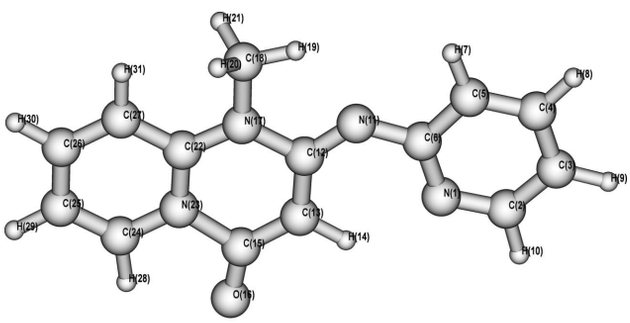
Calculations

DFT calculations were performed at the B3LYP/6-31G* level of theory in order to evaluate whether ketene **11** is a stable minimum or a transition state connecting **9** and **7**. This method was chosen because it has been found to give the best overall

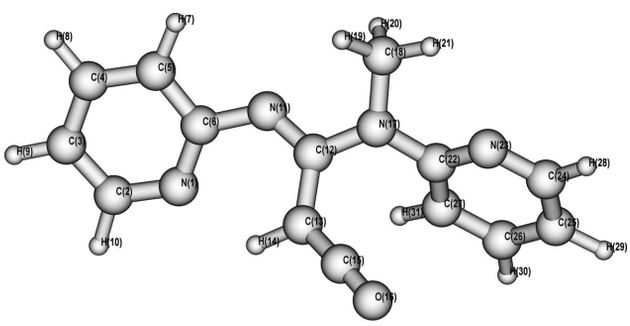
agreement with reference values from higher level calculations.[7] It has also been applied successfully to ketenes in several recent publications,[5,6,8] and specific comparisons with experimental data and with Hartree–Fock, MP2/6-31G*, G2(MP2,SVP) or QCISD(T)/6-31G* calculations of energies, geometries and/or spectra for ketenes have been made.[9] The DFT method has always been found to give excellent agreement with experiment and to compare well with higher level *ab initio* calculations in these studies. The calculations[10] were carried out using the Gaussian 98 suite of programs.[11] Geometry optimizations were performed at the B3LYP/6-31G* (**7a**, **9a**, **11M** and **11TS**)



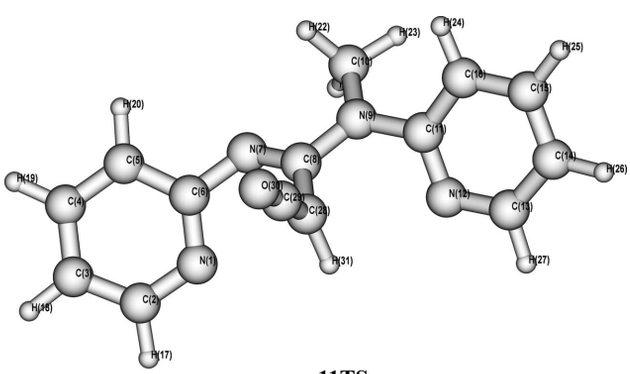
7a



9a

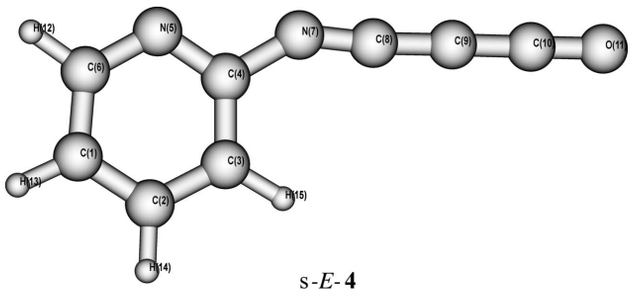


11M

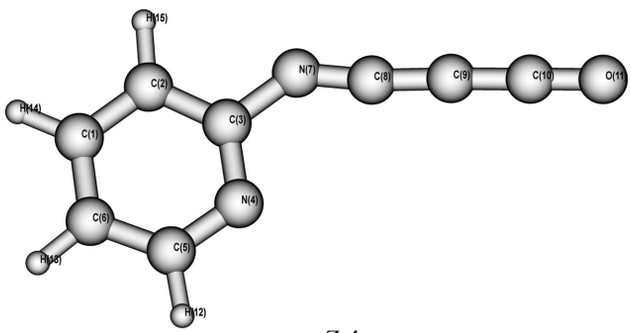


11TS

or the B3LYP/6-31G** (s-*E*- and s-*Z*-**4**) level.[11,12] The B3LYP formulation[9] of density functional theory corresponds to Becke's three-parameter exchange functional[12a] in combination



s-*E*-**4**



s-*Z*-**4**

with the Lee–Yang–Parr correctional functional.[12b] Wavefunction stability, harmonic vibrations and infra-red intensities were calculated at this level in order to characterise the stationary points as minima or saddle points and to evaluate zero-point vibrational energies (ZPVEs). The directly calculated frequencies were scaled by a factor of 0.9613 to account for the overestimation of vibrational frequencies at this level of theory.[13] Improved thermochemical data and dipole moments were obtained through B3LYP/6-311+G(3df,2p) calculations,[11,12] based on the B3LYP/6-31G* (for compounds **7a**, **9a**, the local energy minimum **11M** of ketene **11a**, and the transition state **11TS** for the direct conversion of **9a** to **7a**), or the B3LYP/6-31G** (for compounds s-*E*- and s-*Z*-**4**) optimized geometries, the aggregate methods being B3LYP/6-311+G(3df,2p)//B3LYP/6-31G* and B3LYP/6-311+G(3df,2p)//B3LYP/6-31G**, respectively. Enthalpies were calculated using energy values from the higher level and an unscaled correction from the vibrational frequency calculation at the lower level. Entropies were taken directly from the frequency calculation at the lower level. The free energies were then calculated from these two values. The temperature used in the frequency calculation and hence the energy values was 298.15 K. The transition state structure **11TS** was characterised by having one imaginary frequency and was traced by a systematic alteration of the imino–ketene dihedral angle. Its status as transition state along the reaction path was proved by intrinsic reaction coordinate (IRC) calculations[11] and standard optimisations of the transition state geometry in search of the closest local minima that directly converged to structures **7a** and **9a**, respectively. Standard orientation, dipole moments, thermochemistry and IR spectra of all optimized structures are available as supplementary data.

The calculated energies are reported in Table 1. The free energy of **9a** is *ca*. 53 kJ mol^{-1} above that of **7a**. The ketene **11a** was found to exist in an energy minimum in the conformation **11M** (Scheme 1), which lies *ca*. 105 kJ mol^{-1} above **7a** and *ca*. 52 kJ mol^{-1} above that of **9a**. The transition state **11TS** for the direct conversion of **7a** to **9a** lies *ca*. 31 kJ mol^{-1} above the locally stable conformer **11M**. This last difference can be ascribed to the disruption of conjugation in **11TS**, where the ketene moiety is almost perpendicular to the imine function. Full geometry coordinates are given in the supplementary data. The relative energies and the fragile nature of **11M** explain why such ketenes cannot be observed directly in these reactions,

Table 1 Calculated relative energies at 298.15 K [a]

	ΔH/kJ mol^{-1}	ΔS/JK^{-1} mol^{-1}	ΔG/kJ mol^{-1}
Pyrido[1,2-*a*]pyrimidin-4-one **7a** [b]	0.0	0.0	0.0
Ketene **11** [a]			
11TS	+142.9	+24.6	+135.6
11M	+115.4	+35.5	+104.8
Pyrido[1,2-*a*]pyrimidinium-4-olate **9a** [b]	+52.6	−0.64	+52.8
2-Pyridyliminopropadienone (**4**) [c]			
s-*Z*-**4**	0.0	0.0	0.0
s-*E*-**4**	+4.9	+2.2	+4.2

[a] Cartesian coordinates, dipole moments, thermochemical data and IR spectra for all calculated structures are available in the supplementary data. The relative energies of **7a** and s-*Z*-**4** are arbitrarily set at 0.0. [b] (B3LYP/6-311+(3df,2p)//B3LYP/6-31G* calculations using Gaussian 98. [c] (B3LYP/6-311+(3df,2p)//B3LYP/6-31G** calculations using Gaussian 98.

although their formation from **9** is implied even at room temperature, and from **7** under FVT conditions. Even under matrix isolation conditions, a sufficient population of the stable conformer **11M** would hardly be achieved.

Conclusion

The kinetics, chemistry, and DFT calculations demonstrate that mesoionic pyrido[1,2-*a*]pyrimidinylium olates **9** undergo isomerisation to the lower-energy isomers, the pyridopyrimidinones **7**, slowly at room temperature, and rapidly at 100 °C. This is thought to involve reversible ring opening to the higher-energy ketene valence isomers **11** in solution. However, ketene **11a** only exists in a locally stable conformation **11M**, in which the ketene function is *anti* to the pyridine nitrogen in ring A (see structure **11M** in Scheme 1); in the *syn* conformation spontaneous ring closure to **7a** takes place. Furthermore, the pyridopyrimidines **7** themselves undergo ring opening to unobservable ketenes **11** under FVT conditions, which results in elimination of 2-(methylamino)pyridine **8** and formation of (2-pyridyl)iminopropadienone **4**.

Experimental

The FVT apparatus and general equipment were as previously reported for Ar matrix and preparative scale work (77 K isolation).[11] IR spectra were recorded on a Perkin-Elmer 2000 FTIR spectrometer, and NMR spectra on a Bruker GX 400 NMR spectrometer. GC-MS used a Hewlett-Packard quadrupole detector 5970 with PB-5 capillary column (30 m × 0.25 mm; He carrier at 20 psi head pressure, injector 200 °C, detector 280 °C; column 100–125 °C, programmed at 16 °C min^{-1}). Column chromatography was performed on silica gel 63, 200 mesh. Melting points are uncorrected.

Materials

Compound **5** [15] and the 2-(methylamino)pyridines **8a** and **8b** [16] were prepared according to literature procedures.

2-(*N*-Pyridin-2-yl-*N*-methylamino)-4*H*-pyrido[1,2-*a*]pyrimidin-4-one 7a. A mixture of 2-chloro-4*H*-pyrido[1,2-*a*]-pyrimidin-4-one (**5**, 5.6 mmol, 1.01 g) and 2-(methylamino)-pyridine (**8a**, 14.0 mmol, 1.51 g) was melted and heated in a sealed Schlenk vessel under vacuum at 200 °C for 20 h. After cooling, the dark residue was subjected to column chromatography. Elution with chloroform–ethyl acetate (10 : 1) afforded a mixture of unreacted 2-(methylamino)pyridine and impurities. Elution with ethyl acetate gave **7a** as a yellow oil. The oil was crystallised in ethyl acetate. Yield 34%, 0.48 g. Mp 161–162 °C. GC-MS: *m*/*z* 252 (R_t 18.5 min). Anal. Calcd for $C_{14}H_{12}N_4O$: C 66.66, H 4.79, N 22.21%. Found: C 66.85, H 4.87, N 22.25%. IR: *ν*(Argon, 28 K) 3422 (w), 1714 (s), 1700 (m), 1593 (w), 1564 (m), 1541 (s), 1502 (w), 1476 (s), 1465 (m), 1446 (m), 1435 (s), 1379 (m), 1347 (w), 1329 (w), 1294 (w), 1146 (m), 1123 (w), 771 (w) cm^{-1}. ^{1}H NMR (400.1 MHz, DMSO-d$_6$) *δ*: 8.81 (ddd, $^3J_{6,7}$ 7.1, $^4J_{6,8}$ 0.8, $^5J_{6,9}$ 0.8 Hz, 1H, H-6), 8.46 (ddd, $^3J_{6',5'}$ 4.9, $^4J_{6',4'}$ 2.0, $^5J_{6',3'}$ 0.8 Hz, 1H, H-6′), 7.82 (m, 2H, H-8, H-4′), 7.51 (ddd, $^3J_{9,8}$ 8.2, $^4J_{9,7}$ Hz, $^5J_{9,6}$ 0.9 Hz, 1H, H-9), 7.37 (ddd, $^3J_{3',4'}$ 8.9, $^4J_{3',5'}$ 1.2, $^5J_{3',6'}$ 0.9 Hz, 1H, H-3′), 7.21 (ddd, $^3J_{5',4'}$ 7.3, $^3J_{5',6'}$ 4.9, $^4J_{5',3'}$ 1.0 Hz, 1H, H-5′), 7.15 (ddd, $^3J_{7,8}$ 6.9, $^3J_{7,6}$ 6.9, $^4J_{7,9}$ 1.4 Hz, 1H, H-7), 5.72 (s, 1H, H-3), 3.51 (s, 3H, NCH$_3$). ^{13}C NMR (100.6 MHz, DMSO-d$_6$) *δ*: 160.0 (C-2), 157.1 (C-4), 156.0 (C-2′), 150.0 (C-9a), 148.3 (C-6′), 137.8, 137.7 (C-8, C-4′), 127.0 (C-6), 124.3 (C-3′), 120.3 (C-5′), 120.0 (C-9), 114.1 (C-7), 83.8 (C-3), 35.8 (NCH$_3$). The assignments were supported by a 2D HSQC ^{1}H–^{13}C correlation and a ^{13}C-DEPT spectrum.

2-[*N*-(5-Methylpyridin-2-yl)-*N*-methylamino]-4*H*-pyrido-[1,2-*a*]pyrimidin-4-one 7b. A mixture of **5** (8 mmol, 1.49 g) and 2-(methylamino)-5-methylpyridine (**8b**, 40 mmol, 5.06 g) was melted and heated in a sealed Schlenk vessel under vacuum at 200 °C for 6 h. After cooling, the dark residue was subjected to column chromatography. Elution with ethyl acetate gave **7b**, which was crystallised in ethyl acetate. Yield 49%, 1.08 g. Mp 149 °C. GC-MS: *m*/*z* 266 (R_t 20.4 min). Anal. Calcd for $C_{15}H_{14}N_4O$: C 67.65, H 5.30, N 21.04%. Found: C 67.75, H 5.34, N 20.96%. IR: *ν*(Argon, 23 K) 3732 (m), 1708 (s), 1695 (m), 1684 (m), 1637 (w), 1614 (w), 1600 (m), 1577 (m), 1563 (m), 1543 (s), 1486 (vs), 1445 (s), 1428 (m), 1386 (m), 1378 (m), 1344 (w), 1329 (w), 1295 (w), 1247 (w), 1148 (m), 1121 (m), 771 (m) cm^{-1}. ^{1}H NMR (400.1 MHz, DMSO-d$_6$) *δ*: 8.79 (dd, $^3J_{6,7}$ 7.1, $^4J_{6,8}$ 0.8 Hz, 1H, H-6), 8.29 (dd, $^4J_{6',4'}$ 1.7, $^4J_{6',3'}$ 0.7 Hz, 1H, H-6′), 7.82 (ddd, $^3J_{8,9}$ 9.0, $^3J_{8,7}$ 6.8, $^4J_{8,6}$ 1.8 Hz, 1H, H-8), 7.65 (ddd, $^3J_{9,8}$ 8.2, $^4J_{9,7}$ 2.3, $^5J_{9,6}$ 0.4 Hz, 1H, H-9), 7.38 (d, $^3J_{4',3'}$ 8.2 Hz, 1H, H-4′), 7.34 (d, $^3J_{3',4'}$ 8.3 Hz, 1H, H-3′), 7.12 (ddd, $^3J_{7,8}$ 6.9, $^3J_{7,6}$ 6.8, $^4J_{7,9}$ 1.3 Hz, 1H, H-7), 5.60 (s, 1H, H-3), 3.47 (s, 3H, NCH$_3$), 2.29 (s, 3H, CH$_3$-4′). ^{13}C NMR (100.6 MHz, DMSO-d$_6$) *δ*: 160.1 (C-2), 157.0 (C-4), 153.8 (C-2′), 150.0 (C-9a), 148.3 (C-6′), 138.3 (C-4′), 137.8 (C-8), 127.0 (C-6), 124.2 (C-3′), 129.8 (C-5′), 119.8 (C-9), 113.9 (C-7), 83.0 (C-3), 35.9 (NCH$_3$), 17.3 (CH$_3$-5′) (assignments based on comparison with **7a** and increment calculations).

2-[*N*-(4-Methylpyridin-2-yl)-*N*-methylamino]-4*H*-pyrido-[1,2-*a*]pyrimidin-4-one 7c. A mixture of **5** (8 mmol, 1.52 g) and 2-(methylamino)-4-methylpyridine (**8c**, 40 mmol, 5.04 g) was melted and heated in a sealed Schlenk vessel under vacuum at 200 °C for 4.5 h. After cooling, the dark residue was subjected to column chromatography. Elution with ethyl acetate gave **7c** as oil. The oil was crystallised in ethyl acetate. Yield 44%, 0.98 g. Mp 119–121 °C. GC-MS: *m*/*z* 266 (R_t 19.4 min). Anal. Calcd for $C_{15}H_{14}N_4O$: C 67.65, H 5.30, N 21.04%. Found: C 67.59, H 5.43, N 21.33%. IR: *ν*(Argon, 28 K) 1712 (s), 1700 (vs), 1640

(m), 1610 (m), 1565 (s), 1560 (m), 1541 (vs), 1500 (m), 1496 (m), 1481 (m), 1470 (m), 1447 (vs), 1428 (m), 1415 (s), 1402 (m), 1375 (m), 1344 (w), 1329 (m), 1293 (w), 1277 (w), 1250 (w), 1141 (m), 1121 (m), 1105 (w), 1087 (w), 988 (w), 816 (w), 772 (m) cm^{-1}. ^1H NMR (400.1 MHz, DMSO-d_6) δ: 8.81 (d, $^3J_{6,7}$ 6.8 Hz, 1H, H-6), 8.32 (d, $^3J_{6',5'}$ 5.0 Hz, 1H, H-6′), 7.84 (ddd, $^3J_{8,9}$ 8.9, $^3J_{8,7}$ 6.9, $^4J_{8,6}$ 1.7 Hz, 1H, H-8), 7.39 (d, $^3J_{9,8}$ 8.9 Hz, 1H, H-9), 7.33 (s, 1H, H-3′), 7.14 (ddd, $^3J_{7,8}$ 6.9, $^3J_{7,6}$ 6.8, $^4J_{7,9}$ 1.1 Hz, 1H, H-7), 7.06 (d, $^3J_{5',6'}$ 5.0 Hz, 1H, H-5′), 5.66 (s, 1H, H-3), 3.49 (s, 3H, NCH_3), 2.33 (s, 3H, CH_3-4′). ^{13}C NMR (100.6 MHz, DMSO-d_6) δ: 160.1 (C-2), 157.0 (C-4), 156.2 (C-2′), 150.0 (C-9a), 148.7 (C-4′), 148.0 (C-6′), 137.8 (C-8), 127.0 (C-6), 124.3 (C-3′), 121.6 (C-5′), 120.3 (C-9), 114.1 (C-7), 83.6 (C-3), 35.9 (NCH_3), 20.5 (CH_3-4′) (assignments based on comparison with **7a** and increment calculations).

Preparative flash vacuum thermolysis

Pyridopyrimidinones were sublimed and subjected to preparative flash vacuum thermolysis at 860 °C and 10^{-4} mbar. The products were collected on a liquid nitrogen-cooled cold finger. Upon completion of the thermolysis, the system was isolated from the pump and brought to atmospheric pressure with nitrogen. The liquid nitrogen was removed from the cold finger, which was rinsed with dichloromethane.

Preparative FVT of 7a–c

After warm-up to room temperature, the solvent was evaporated and the oily residue subjected to column chromatography. Elution with ethyl acetate–acetone (1 : 1) afforded a mixture of unreacted precursor and impurities. Elution with ethyl acetate–methanol (3 : 1) gave the mesoionic products, **9a**–**10a**, **9b**–**10b**, and **9c**–**10c** as yellow–orange crystals. Pure samples of **10b** and **10c** were obtained by selective thermal destruction of **9b** and **9c** as described below. The reported yields are based on NMR integrations.

1-Methyl-2-(*N*-pyridin-2-ylimino)-2*H*-pyrido[1,2-*a*]pyrimidin-1-ium-4-olate 9a. Compound **7a** (0.27 mmol, 68 mg) was sublimed at 95–100 °C. Yield of **9a** 51% (together with 16% of **10a**, see data below). MS: *m*/*z* 252 (37), 251 (45), 225 (12), 224 (75), 223 (18), 162 (15), 146 (47), 145 (9), 131 (13), 119 (8), 118 (12), 107 (18), 79 (24), 78 (100), 52 (10), 51 (21%). ^1H NMR (400.1 MHz, DMSO-d_6) δ: 9.08 (dd, $^3J_{6,7}$ 6.8, $^4J_{6,8}$ 1.5 Hz, 1H, H-6), 8.28 (ddd, $^3J_{6',5'}$ 5.0, $^4J_{6',4'}$ 2.0, $^5J_{6',3'}$ 0.8 Hz, 1H, H-6′), 8.25 (ddd, $^3J_{8,9}$ 9.0, $^3J_{8,7}$ 7.1, $^4J_{8,6}$ 1.8 Hz, 1H, H-8), 7.79 (d, $^3J_{9,8}$ 9.0 Hz, 1H, H-9), 7.61 (ddd, $^3J_{4',3'}$ 8.0, $^3J_{4',5'}$ 7.3, $^4J_{4',6'}$ 2.0 Hz, 1H, H-4′), 7.39 (ddd, $^3J_{7,8}$ 6.9, $^3J_{7,6}$ 6.8, $^4J_{7,9}$ 1.0 Hz, 1H, H-7), 6.87 (ddd, $^3J_{5',4'}$ 7.2, $^3J_{5',6'}$ 4.9, $^4J_{5',3'}$ 1.1 Hz, 1H, H-5′), 6.78 (ddd, $^3J_{3',4'}$ 8.0, $^4J_{3',5'}$ 0.9, $^5J_{3',6'}$ 0.9 Hz, 1H, H-3′), 5.39 (s, 1H, H-3), 3.78 (s, 3H, CH_3-1). ^{13}C NMR (100.6 MHz, DMSO-d_6) δ: 162.4 (C-2), 151.9 (C-4), 151.5 (C-2′), 148.2 (C-6′), 148.1 (C-9a), 143.4 (C-8), 137.4 (C-4′), 130.5 (C-6), 118.0 (C-3′), 116.6 (C-5′), 115.3 (C-7), 114.7 (C-9), 76.5 (C-3), 31.0 (CH_3-1). The assignments were supported by a 2D HSQC ^1H–^{13}C correlation and a ^{13}C-DEPT spectrum.

1-Methyl-4-(*N*-pyridin-2-ylimino)-4*H*-pyrido[1,2-*a*]pyrimidin-1-ium-2-olate 10a. This compound was obtained in 16% yield in a mixture with the foregoing compound **9a**. ^1H NMR (400.1 MHz, DMSO-d_6) δ: 9.85 (dd, $^3J_{6,7}$ 6.9, $^4J_{6,8}$ 1.3 Hz, 1H, H-6), 8.36 (ddd, $^3J_{8,9}$ 8.9, $^3J_{8,7}$ 7.1, $^4J_{8,6}$ 1.8 Hz, 1H, H-8), 8.23 (dd, $^3J_{6',5}$ 5.7, $^4J_{6',4'}$ 1.2 Hz, 1H, H-6′), 7.87 (d, $^3J_{9,8}$ 9.1 Hz, 1H, H-9), 7.68 (ddd, $^3J_{4',3'}$ 7.9, $^3J_{4',5'}$ 7.0, $^4J_{4',6'}$ 2.1 Hz, 1H, H-4′), 7.55 (ddd, $^3J_{7,8}$ 7.0, $^3J_{7,6}$ 7.0, $^4J_{7,9}$ 1.2 Hz, 1H, H-7), 7.05 (d, $^3J_{3',4'}$ 8.5 Hz, 1H, H-3′), 6.84 (ddd, $^3J_{5',4'}$ 7.0, $^3J_{5',6'}$ 5.2, $^4J_{5',3'}$ 1.2 Hz, 1H, H-5′), 6.36 (s, 1H, H-3), 3.60 (s, 3H, CH_3-1). ^{13}C NMR (100.6 MHz, DMSO-d_6) δ: 161.4 (C-2), 157.3 (C-4), 148.0 (C-2′), 147.6 (C-9a), 147.5 (C-6′), 143.0 (C-8), 136.9 (C-4′), 131.3 (C-6), 119.5 (C-3′), 115.8 (C-7), 115.7 (C-5′), 114.9 (C-9), 81.4 (C-3), 29.1 (CH_3-1). The assignments were supported by a ^{13}C-DEPT spectrum.

Kinetic experiment. Compound **9a** converts to **7a** to the extent of 10% in the course of one month at room temperature (DMSO-d_6 solution). At 100 °C complete conversion was obtained after 15 min. The reaction was followed kinetically by ^1H NMR at 75 °C by heating the mixture of **9a** and **10a** (the latter is stable under these conditions). The signal height at 5.39 ppm was observed at 5 min intervals for 165 min. A plot of reaction time *versus* signal height at 5.39 ppm had a shape of an exponential function, which is characteristic of a first order reaction. A plot of reaction time *versus* ln ($[X]_0$/[X]) gives a straight line with a slope of 0.0135 in conformity with a first order reaction with a half-life $t_{1/2} = 51$ min. The data and graphs (1 and 2 order fits) are given in the supplementary data.

1,7-Dimethyl-2-(*N*-pyridin-2-ylimino)-2*H*-pyrido[1,2-*a*]pyrimidin-1-ium-4-olate 9b. Compound **7b** (0.49 mmol, 130 mg) was sublimed at 150 °C. The product consisted of a mixture of **9b** (60% yield) and **10b** (25% yield). In order to separate **9b** and **10b**, the mixture was dissolved in ethyl acetate and heated at 100 °C for 15 min. During the heating **9b** rearranged to **7b**. Column chromatography on silica gel with ethyl acetate gave **7b**, and with ethyl acetate–methanol (3 : 10) **10b**. Data for **9b**: ^1H NMR (400.1 MHz, DMSO-d_6) δ: 8.90 (s 1H, H-6), 8.26 (ddd, $^3J_{6',5'}$ 4.9, $^4J_{6',4'}$ 2.0, $^5J_{6',3'}$ 0.6 Hz, 1H, H-6′), 8.13 (d, $^3J_{8,9}$ 9.1 Hz, 1H, H-8), 7.73 (d, $^3J_{9,8}$ 9.1 Hz, 1H, H-9), 7.60 (ddd, $^3J_{4',3'}$ 8.0, $^3J_{4',5'}$ 7.3, $^4J_{4',6'}$ 2.0 Hz, 1H, H-4′), 6.85 (ddd, $^3J_{5',4'}$ 7.3, $^3J_{5',6'}$ 4.9, $^4J_{5',3'}$ 1.0 Hz, 1H, H-5′), 6.77 (d, $^3J_{3',4'}$ 8.1 Hz, 1H, H-3′), 5.40 (s, 1H, H-3), 3.76 (s, 3H, CH_3-1), 2.37 (s, 3H, CH_3-7). ^{13}C NMR (100.6 MHz, DMSO-d_6) δ: 162.4 (C-2), 151.9 (C-4), 151.6 (C-2′), 148.1 (C-6′), 146.6 (C-9a), 145.2 (C-8), 137.4 (C-4′), 128.4 (C-6), 125.2 (C-7), 118.1 (C-3′), 116.5 (C-5′), 114.4 (C-9), 76.7 (C-3), 31.0 (CH_3-1), 17.0 (CH_3-7). The assignments were supported by a ^{13}C-DEPT spectrum.

1,7-Dimethyl-4-(*N*-pyridin-2-ylimino)-4*H*-pyrido[1,2-*a*]pyrimidin-1-ium-2-olate 10b. This compound was obtained in 25% isolated yield and isolated as described above. Mp (decomp.) >300 °C. MS: *m*/*z* 267 (14), 266 (82), 265 (80), 238 (34), 237 (13), 163 (12), 162 (100), 161 (15), 160 (8), 146 (21), 145 (25), 133 (21), 122 (23), 121 (47), 119 (12), 118 (12), 94 (27), 93 (43), 92 (17), 79 (9), 78 (89), 66 (9), 65 (14), 52 (8), 51 (15), 44 (8), 39 (8%). HRMS Calcd. for $C_{15}H_{14}N_4O$: *m*/*z* 266.11621. Found: *m*/*z* 266.11624. ^1H NMR (400.1 MHz, DMSO-d_6) δ: 9.78 (s, 1H, H-6), 8.27 (dd, $^3J_{6',5'}$ 4.8, $^4J_{6',4'}$ 1.5 Hz, 1H, H-6′), 8.21 (d, $^3J_{8,9}$ 9.1 Hz, 1H, H-8), 7.77 (d, $^3J_{9,8}$ 9.1 Hz, 1H, H-9), 7.57 (ddd, $^3J_{4',3'}$ 8.1, $^3J_{4',5'}$ 7.2, $^4J_{4',6'}$ 2.1 Hz, 1H, H-4′), 6.92 (d, $^3J_{3',4'}$ 8.1 Hz, 1H, H-3′), 6.79 (ddd, $^3J_{5',4'}$ 7.1, $^3J_{5',6'}$ 5.0, $^4J_{5',3'}$ 1.0 Hz, 1H, H-5′), 6.36 (s, 1H, H-3), 3.36 (s, 3H, CH_3-1), 2.45 (s, 3H, CH_3-7). ^{13}C NMR (100.6 MHz, DMSO-d_6) δ: 161.5 (C-2), 157.3 (C-4), 147.9 (C-2′), 147.6 (C-6′), 146.2 (C-9a), 144.9 (C-8), 136.8 (C-4′), 129.0 (C-6), 125.4 (C-7), 119.4 (C-3′), 115.6 (C-5′), 114.6 (C-9), 81.3 (C-3), 29.1 (CH_3-1), 17.3 (CH_3-7). The assignments were supported by a ^{13}C-DEPT spectrum.

1,8-Dimethyl-2-(*N*-pyridin-2-ylimino)-2*H*-pyrido[1,2-*a*]pyrimidin-1-ium-4-olate 9c. Compound **7c** (0.53 mmol, 140 mg) was sublimed at 140–150 °C. The product consisted of a mixture of **9c** (68% yield) and 11% of **10c** (11%; see data below). In order to separate **9c** and **10c**, the mixture was dissolved in ethyl acetate and heated at 100 °C for 15 min. During the heating **9c** rearranged to **7c**. Column chromatography on silica gel with ethyl acetate gave **7c**, and with ethyl acetate–methanol (3 : 10) **10c**. Data for **9c**: MS: *m*/*z* 266 (41), 265 (49), 239 (17), 238 (100), 237 (24), 146 (53), 145 (18), 133 (11), 121 (20), 119 (14), 118 (12), 93 (17), 92 (13), 78 (66), 65 (9), 51 (10%). ^1H NMR (400.1 MHz, DMSO-d_6) δ: 8.93 (d, $^3J_{6,7}$ 6.9 Hz, 1H, H-6), 8.27 (ddd,

$^3J_{6',5'}$ 5.0, $^4J_{6',4'}$ 2.0, $^5J_{6',3'}$ 0.8 Hz, 1H, H-6′), 7.66 (s, 1H, H-9), 7.61 (ddd, $^3J_{4',3'}$ 8.1, $^3J_{4',5'}$ 7.3, $^4J_{4',6'}$ 2.1 Hz, 1H, H-4′), 7.25 (d, $^3J_{7,8}$ 7.0 Hz, 1H, H-7), 6.86 (ddd, $^3J_{5',4'}$ 7.3, $^3J_{5',6'}$ 4.9, $^4J_{5',3'}$ 1.1 Hz, 1H, H-5′), 6.78 (ddd, $^3J_{3',4'}$ 8.1, $^4J_{3',5'}$ 0.9, $^5J_{3',6'}$ 0.9 Hz, 1H, H-3′), 5.34 (s, 1H, H-3), 3.76 (s, 3H, CH_3-1), 2.54 (s, 3H, CH_3-8). ^{13}C NMR (100.6 MHz, DMSO-d_6) δ: 162.4 (C-2), 156.3 (C-8), 152.1 (C-4), 151.6 (C-2′), 148.1 (C-6′), 147.6 (C-9a), 137.4 (C-4′), 129.8 (C-6), 118.0 (C-3′), 117.2 (C-7), 116.5 (C-5′), 113.5 (C-9), 76.1 (C-3), 31.0 (CH_3-1), 21.5 (CH_3-8). The assignments were supported by a ^{13}C-DEPT spectrum.

1,8-Dimethyl-4-(*N*-pyridin-2-ylimino)-4*H*-pyrido[1,2-*a*]-pyrimidin-1-ium-2-olate 10c. This compound was obtained in 11% yield and isolated as described above. Mp (decomp.) >300 °C. HRMS Calcd for $C_{15}H_{14}N_4O$: *m*/*z* 266.11621. Found: *m*/*z* 266.11625. ^{1}H NMR (400.1 MHz, DMSO-d_6) δ: 9.81 (d, $^3J_{6,7}$ 7.2 Hz, 1H, H-6), 8.26 (ddd, $^3J_{6',5'}$ 5.0, $^4J_{6',4'}$ 2.1, $^5J_{6',3'}$ 0.9 Hz, 1H, H-6′), 7.66 (s, 1H, H-9), 7.56 (ddd, $^3J_{4',3'}$ 8.2, $^3J_{4',5'}$ 7.0, $^4J_{4',6'}$ 2.1 Hz, 1H, H-4′), 7.36 (d, $^3J_{7,8}$ 7.2 Hz, 1H, H-7), 6.89 (ddd, $^3J_{3',4'}$ 7.9, $^4J_{3',5'}$ 1.1, $^5J_{3',6'}$ 0.9 Hz, 1H, H-3′), 6.78 (ddd, $^3J_{5',4'}$ 7.2, $^3J_{5',6'}$ 5.1, $^4J_{5',3'}$ 1.0 Hz, 1H, H-5′), 6.35 (s, 1H, H-3), 3.54 (s, 3H, CH_3-1), 2.57 (s, 3H, CH_3-8). ^{13}C NMR (100.6 MHz, DMSO-d_6) δ: 161.5 (C-2), 157.5 (C-4), 155.9 (C-8), 147.9 (C-2′), 147.4 (C-6′), 147.1 (C-9a), 136.9 (C-4′), 130.6 (C-6), 119.4 (C-3′), 117.6 (C-7), 115.5 (C-5′), 113.6 (C-9), 80.9 (C-3), 29.1 (CH_3-1), 21.4 (CH_3-8). The assignments were supported by a ^{13}C-DEPT spectrum.

FVT–matrix isolation

The pyridopyrimidinones **7** (*ca*. 10 mg portions) were placed in the quartz thermolysis tube in an oven directly attached to the vacuum system. After evacuating the system, the cryostat was turned on and the pressure brought to 10^{-5} mbar while the CsI disk reached a temperature of 7 K. Argon was passed over the sample while it was sublimed through the FVT tube maintained at different temperatures. The products were co-deposited on the disk at 7 K for FTIR spectroscopy.

FVT of 7a. This compound was subjected to FVT at 800, 825 and 860 °C. The sublimation temperature was 90–100 °C. At 800 and 825 °C, mainly **4** (2249 cm^{-1}) and a small amount of starting material **7a** (1714 cm^{-1}) were observed. At 860 °C, the formation of **4** was essentially complete, ν_{max}(Ar, 7 K)/cm^{-1} 2250 (vs), 2128 (m), 1611 (m), 1587 (w), 1567 (w), 1459 (w), 1433 (w), 1294 (w), 1261 (w), 1220 (w), 776 (w). See the supplementary data for experimental and calculated spectra (B3LYP/6-31G**). Bands due to 2-(methylamino)pyridine were present at 1617, 1611, 1603, 1579, 1524, 1511, 1459, 1421, 1329, 1289, 1148 and 771 cm^{-1}. IR spectrum of authentic 2-(methylamino)pyridine (obtained by sublimation at 10 °C; Ar matrix, 23 K): 3502–2821m (broad), 1613 (s), 1606 (s), 1602 (vs), 1578 (m), 1574 (m), 1524 (s), 1511 (s), 1493 (w), 1464 (w), 1459 (m), 1440 (w), 1429 (w), 1421 (s), 1414 (m), 1337 (w), 1329 (w), 1289 (m), 1169 (w), 1156 (w), 1149 (w), 1131 (w), 1089 (w), 1074 (w), 981 (w), 772 (s), 734 (w), 522 (w) cm^{-1}.

FVT of 7b. This compound was subjected to FVT at 860 °C. Sublimation temperature: 70 °C. The product bands in the Ar matrix spectrum were identified as (2-pyridyl)iminopropadienone **4** and 2-methylamino-5-methylpyridine **8b**. No starting material **7b** (1710 cm^{-1}) was observed in the spectra. See the supplementary data for listed spectra.

FVT of 7c. This compound was subjected to FVT at 860 °C. Sublimation temperature: 80–90 °C. The product bands in the Ar matrix spectrum showed the formation of **4** and 2-(methylamino)-4-methylpyridine **8c**. No starting material **7c** (1700 cm^{-1}) was observed in the spectra. See the supplementary data for listed spectra.

FVT–warm-up experiment

The pyridopyrimidinone **7a** (*ca*. 50 mg) was subjected to FVT at 900 °C with Ar being passed over the sample while it was sublimed at 90–110 °C. The products of the FVT reaction were isolated on the CsI disk at 50 K (*i.e.* Ar not condensing). The main peak of **4** appeared at 2239 cm^{-1} under these conditions. The cryostat was turned off, and IR spectra were recorded for every 10 K increase in temperature until the CsI disk reached room temperature. Plotting of the area of the peak at 2239 cm^{-1} *versus* the temperature of the CsI disk showed that **4** was stable up to 180 K.

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