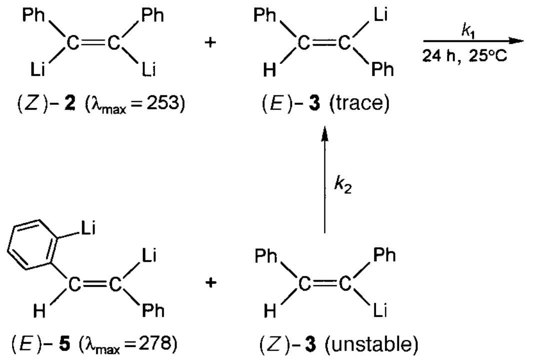
stilbene (*E*)-**3**. Its lithiation by (*Z*)-**2** then produces *ortho*-lithiated (*E*)-**5**, which absorbs at 278 nm and is the final product of the 253–278 conversion.

The proposed mechanism accounts for the formation of the *trans*-stilbene carrying two deuterium atoms, one vinylic and one aromatic, upon addition of MeOD. The monolithium adduct (*E*)-**3**, but not (*Z*)-**3**, is lithiated by (*Z*)-**2** since the agostic effect[15] of its vinylic lithium atom activates its *ortho* proton. The lack of activation of the (*Z*)-**3** protons accounts for its inertness. The isomerization of (*Z*)-**3** to (*E*)-**3** regenerates the latter and allows for the repetition of the process.



The 253–278 conversion is expected to accelerate on addition of the independently prepared intermediate (*E*)-**3** to the solution of the primary dilithium adduct (*Z*)-**2** in diethyl ether. This has been experimentally verified.[10] A solution of (*E*)-**3** (5 mmol), prepared by allowing lithium to react with α-chloro-*trans*-stilbene in diethyl ether, was added to one of two aliquots (6 mmol each) of the primary solution of the dilithium adduct (*Z*)-**2** in diethyl ether. After both aliquots had been kept at 20 °C for four hours, the analysis showed 10 % conversion in the aliquot containing the added (*E*)-**3**, but only 2 % in the other.

The intermediate (*E*)-**3** is continually formed through the isomerization of (*Z*)-**3** and destroyed by its reaction with (*Z*)-**2**. It is plausible to assume that its minute concentration is stationary, that is, $\mathrm{d}[(E)\text{-}\mathbf{3}]/\mathrm{d}t = k_2[(Z)\text{-}\mathbf{3}] - k_1[(Z)\text{-}\mathbf{2}]\cdot[(E)\text{-}\mathbf{3}] = 0$. Hence, $[(E)\text{-}\mathbf{3}] = k_2[(Z)\text{-}\mathbf{3}]/k_1[(Z)\text{-}\mathbf{2}]$, and the rate of the 253–278 conversion, equal to $k_1[(Z)\text{-}\mathbf{2}]\cdot[(E)\text{-}\mathbf{3}]$, is $k_2[(Z)\text{-}\mathbf{3}]$; that is it is constant for a constant concentration of (*Z*)-**3** but increases with increasing concentration of (*Z*)-**3**. The observed zero-order kinetics of the conversion is therefore accounted for at low concentrations of (*E*)-**3**.

Experimental Section

High-vacuum technique was used during this study. The oxides coating the chunks of lithium are stripped away by keeping the metal for a few hours in a solution of anthracene in diethyl ether. Shaking and decanting removed the anthracene and the stripped residues (see reference [16] for details of this operation to leave the chunks with a silvery surface). The stilbenes were isolated by evaporation of the solvents, and the residues were then recrystallized.

Received: January 26, 1997 [Z11409IE]
German version: *Angew. Chem.* **1998**, *110*, 2216–2218

Keywords: agostic interactions · kinetics · lithium · rearrangements · reductions

[1] G. Levin, J. Jagur-Grodzinski, M. Szwarc, *J. Am. Chem. Soc.* **1970**, *92*, 2268–2275.
[2] R. Knorr, E. Lattke, *Tetrahedron Lett.* **1977**, 3969–3972.
[3] *Ions and Ion-Pairs in Organic Reactions* (Ed.: M. Szwarc), Wiley, New York, **1972**.
[4] T. E. Hogen-Esch, *Adv. Phys. Org. Chem.* **1977**, *15*, 153–266.
[5] J. W. Bausch, P. S. Gregory, G. A. Olah, G. K. S. Prakash, P. von R. Schleyer, G. A. Segal, *J. Am. Chem. Soc.* **1989**, *111*, 3633–3640.
[6] C. Lambert, P. von R. Schleyer, *Angew. Chem.* **1994**, *106*, 1187–1199; *Angew. Chem. Int. Ed. Engl.* **1994**, *33*, 1129-1140.
[7] G. Levin, B. E. Holloway, M. Szwarc, *J. Am. Chem. Soc.* **1976**, *98*, 5706–5709.
[8] Y. Apeloig, T. Clark, A. J. Kos, E. D. Jemmis, P. von R. Schleyer, *Israel J. Chem.* **1980**, *20*, 43–50.
[9] A. Maercker, U. Girreser, *Angew. Chem.* **1990**, *102*, 718–720; *Angew. Chem. Int. Ed. Engl.* **1990**, *29*, 667–669.
[10] M. Kemmer, *Darstellung von vicinalen Dilithioalkenen, Stabilitäten und Folgereaktionen*, Shaker, **1997**.
[11] P. von R. Schleyer, E. Kaufmann, A. J. Kos, T. Clark, J. A. Pople, *Angew. Chem.* **1986**, *98*, 164–165; *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 169–170.
[12] E. E. Bolton, W. D. Laidig, P. von R. Schleyer, H. F. Schaefer III, *J. Am. Chem. Soc.* **1994**, *116*, 9602–9612, and references therein.
[13] A. Maercker, U. Girreser, *Tetrahedron* **1994**, *50*, 8019–8034.
[14] A. Maercker, T. Graule, W. Demuth, *Angew. Chem.* **1987**, *99*, 1075–1076; *Angew. Chem. Int. Ed. Engl.* **1987**, *26*, 1032–1034.
[15] W. Bauer, M. Feigel, G. Müller, P. von R. Schleyer, *J. Am. Chem. Soc.* **1988,** *110*, 6033–6046.
[16] M. Szwarc, *Carbanions, Living Polymers, and Electron Transfer Processes*, Wiley-Interscience, New York, **1968**, pp. 151–188.

Rearrangement of 5-Substituted 5-Aminopentadienals**

Fabian Fischer, Daniel Berger, and
Markus Neuenschwander*

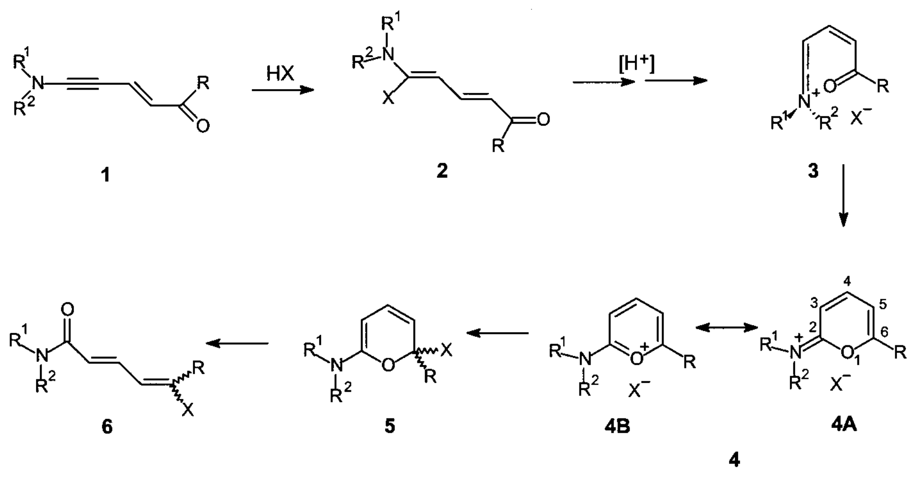
*Dedicated to Professor Klaus Hafner
on the occasion of his 70th birthday*

As typical “push–pull” (PP) acetylenes,[1] dialkylaminopropinals react easily with carboxylic acids and HCl to give 3-X-substituted 3-aminopropenals, which nearly quantitatively rearrange to 3-acyloxy- and 3-chloroacrylicamides.[2, 3] Similarly, PP-enynes of type **1** are expected to add acids, while the hereby formed 5-substituted 5-aminopenta-2,4-dien-1-als **2** could be prone to a vinylogous rearrangement to give 5-substituted pentadienecarboxamides **6** after extrusion of X^- (**2**→**3**), ring closure (**3**→**4**), addition of X^- (**4**→**5**), and ring opening (**5**→**6**). Whereas simple PP-enynes **1** remained unknown for a long time,[4] they have been made available recently by two synthetic sequences.[5, 6] As a result, reactions of **1** with acids may be investigated in more detail now.

---

[*] Prof. Dr. M. Neuenschwander, Dr. F. Fischer, Dr. D. Berger
Departement für Chemie und Biochemie der Universität
Freiestrasse 3, CH-3012 Bern (Switzerland)
Fax: (+41) 31-631-3426

[**] Aminoacrylic Compounds, Part 31. This work has been supported by the Swiss National Foundation (project no. 20–50331.97). Part 30: reference [7].



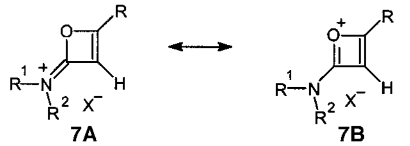
a $R^1 = R^2 = Me$, R = H; **b** $R^1, R^2 = (CH_2)_2O(CH_2)_2$, R = H; **c** $R^1 = Me$, $R^2 = Ph$, R = H;
d $R^1 = R^2 = Me$, R = Me; **e** $R^1, R^2 = (CH_2)_2O(CH_2)_2$, R = Me; **f** $R^1 = Me$, $R^2 = Ph$, R = Me;
g R^1, R^2 = CH=CH-N-CH=CH, R = H

In fact, PP-enynes react with carboxylic acids (e.g. HOAc[7]) and hydrogen halides HF, HCl,[7] HBr, and HI to give *trans*-addition products **2**[8] with high yields; these may be isolated (X = OAc, Cl, F)[9] or spectroscopically identified in most cases. Qualitatively, reaction rates for **1** + HX → **2** increase with acidity of HX. For example, additions of HF or HOAc are considerably slower than those of HCl, HBr, or HI, whereas uncatalyzed additions of phenol are very slow (50 % conversion after two to four days).

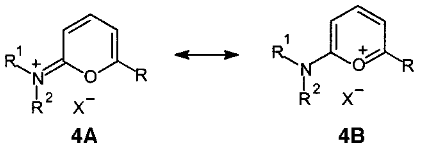
In most cases, compounds **2** rearrange to form 2-aminopyrylium salts **4** with high yields in the presence of acids, and the reaction rates of conversions **2** → **4** are strongly influenced by the ability of X to act as a leaving group. Thus, reactions of 5-substituted 5-aminopentadienals **2** bearing good leaving groups (X = Cl, Br, I) are so fast that it is not easy to isolate the corresponding addition products **2** for X = Br, I. The consequence is that salts **4** are conveniently available in a simple one-pot procedure by treating PP-enynes **1** with 1.05 molar equivalents of HCl, HBr, or HI.[9, 10] On the other hand, compounds **2** bearing comparably bad leaving groups (X = F, OAc) only react in the presence of a large excess of acid. These results favor acid-catalyzed cleavage of the leaving group X (**2** → **3**) to be the rate-determining step in the reaction **2** → **4**.

2-Aminopyrylium halides **4** (X = F, Cl, Br, I) are quite unreactive[11] and are not prone to spontaneous ring openings to form 5-halopentadienecarboxamides **6**. In that respect, compounds **2** (X = Cl) are very different from 3-amino-3-chloroacroleins, which rearrange to 3-chloroacrylicamides[2, 3] at 0 °C in the presence of traces of acid; the sequence proceeds over oxetene immonium salts **7** as intermediates, according to mechanistic investigations.[12] We believe that the different behavior is related to the considerable difference in energy between intermediates **7** and **4**: Oxetene immonium salts **7** are highly strained molecules without any resonance stabilization (**7B**[13]), while 2-aminopyrylium salts **4** are essentially strain-free compounds whose energy decreases due to π delocalization (**4B**[13]). This reasonably explains why salts **4** with weakly nucleophilic counterions X^- are not prone to an easy ring opening of the type **4** → **6**. In the following we will show that the "aminopentadienal rearrangement"[14] may take place at low temperatures (0–20 °C) in the presence of stronger nucleophiles.[15]

5-Morpholinopent-2-en-4-in-1-al (**1b**) nearly quantitatively adds acetic acid to give **2b** (X = OAc), which rearranges to the corresponding 2-aminopyrylium acetate **4b** (X = OAc, ca. 90 % yield) only in an excess of HOAc (ca. 25 molar equiv). In the absence of a further nucleophile, no ring opening **4b** → **6b** (X = OAc) is observed. However, if Et_3N is added to a solution of **4b** (X = OAc) in CH_2Cl_2, then **6b** (X = OAc) may be isolated in moderate yields (23 %).[16] Similarly, **4b** (X = OAc) as well as **4b** (X = F) rearrange in an excess of EtOH to give **6b** (X = OEt, 33 %).



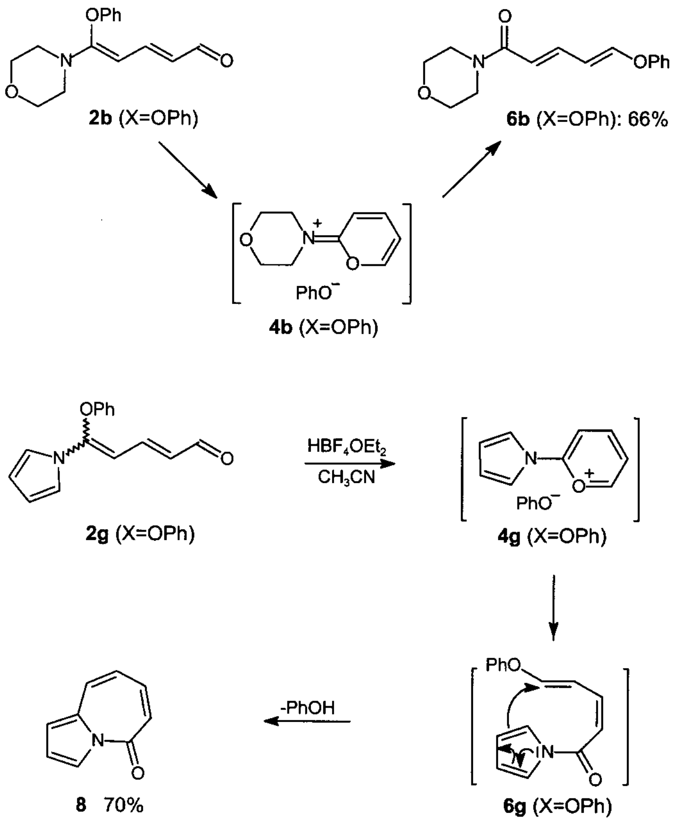
7



4

For realizing faster aminopentadienal rearrangements[14] **2** → → **4** → → **6**, salts **4** with more nucleophilic counterions X^- are needed. For example, phenol adds very slowly in the reaction **1b** → **2b** (X = OPh). According to ^1H NMR spectroscopy (300 MHz, $CDCl_3$, 20 °C), a maximum concentration of **2b** (X = OPh) is observed after about four days. Quite surprisingly, 2-aminopyrylium phenolate **4b** (X = OPh) is not directly observed by NMR spectroscopy because nucleophilic attack of phenol **4b** → **5b** is too fast. Considering the low reaction rate of the addition of phenol to **1b**, the overall yield of 66 % for the isolated morpholinamide **6b** (X = OPh) is remarkable.

Finally, a quite spectacular rearrangement sequence is observed for (*Z*/*E*)-**2g** (X = OPh) in the presence of HBF_4: Ring closure (**2g** → **4g**, X = OPh) followed by ring opening (**4g** → **6g**) and final addition/elimination (**6g** → **8** + PhOH) gives the well-known[17] 3a-aza-azulen-4-one **8**.



These results show that PP-enynes **1** react with a variety of acids, while the hereby formed addition products **2** easily rearrange in most cases (X = Cl, Br, I) to give 2-aminopyrylium salts **4**. On the other hand, the postulated ring-opening reaction **4**→→**6** only proceeds in the presence of nucleophilic counterions.

Received: February 16, 1998 [Z11485IE]
German version: *Angew. Chem.* **1998**, *110*, 2214–2216

Keywords: aminopentadienals · donor–acceptor systems · enynes · pyrylium salts · rearrangements

---

[1] Important syntheses: a) K. Hafner, M. Neuenschwander, *Angew. Chem.* **1968**, *80*, 443–444; *Angew. Chem. Int. Ed. Engl.* **1968**, *7*, 459–460; b) M. E. Kuehne, P. J. Sheeran, *J. Org. Chem.* **1968**, *33*, 4406–4413; c) G. Himbert, M. Regitz, *Synthesis* **1972**, 571–573; d) G. Himbert, *Angew. Chem.* **1979**, *91*, 432–433; *Angew. Chem. Int. Ed. Engl.* **1979**, *18*, 405; e) T. Sasaki, A. Kojima, *J. Chem. Soc. C* **1970**, 476–480.

[2] a) M. Neuenschwander, K. Hafner, *Angew. Chem.* **1968**, *80*, 444; *Angew. Chem. Int. Ed. Engl.* **1968**, *7*, 460; b) H. J. Gais, K. Hafner, M. Neuenschwander, *Helv. Chim. Acta* **1969**, *52*, 2641–2657.

[3] W. Steglich, G. Höfle, W. König, F. Weygand, *Chem. Ber.* **1968**, *101*, 308–322.

[4] For the synthesis of two highly substituted PP-enynes of type **1**, see Y. Sato, Y. Kobayashi, M. Sugiura, H. Shirai, *J. Org. Chem.* **1978**, *43*, 199–202; G. Himbert, W. Brunn, *Liebigs Ann. Chem.* **1985**, 2206–2216.

[5] Three PP-enynes **1** have been prepared in a surprisingly simple way by aldol condensation of PP-acetylenes[1] with ketones: I. G. Ostroumov, E.Yu. Khakunova, A. E. Tsil'ko, I. A. Maretina, A. A. Petrov, *Zh. Org. Khim.* **1990**, *26*, 2508–2510; *J. Org. Chem. USSR* (*Engl. Transl.*) **1990**, *26*, 2172–2173.

[6] Compared with the aldol condensation of PP-acetylenes described in ref. [6], Pd^0-catalyzed coupling of trialkylsilyl- or trialkylstannylynamines with 3-iodopropenal or 4-iodobut-3-en-2-one has a much broader scope and makes aldehydes **1a–c** and **1g** (R = H) available as well: a) A. Bartlome, U. Stämpfli, M. Neuenschwander, *Chimia* **1991**, *45*, 346–349; b) D. Berger, Dissertation, Universität Bern, **1995**; c) D. Berger, A. Bartlome, M. Neuenschwander, *Helv. Chim. Acta* **1996**, *79*, 179–191; d) F. Fischer, Dissertation, Universität Bern, **1998**.

[7] D. Berger, M. Neuenschwander, *Helv. Chim. Acta* **1996**, *79*, 192–202.

[8] Mechanistic considerations (for a discussions see ref. [7]) suggest that reactions of acids with **1** should give *Z*/*E* mixtures of **2**, which could isomerize to the thermodynamically favored *Z* isomer due to a pronounced π delocalization of **2** (or of protonated **2**).

[9] For illustrations of the ^{1}H NMR, ^{13}C NMR, IR, UV, and mass spectra of **1**, **2**, **4**, and **6** as well as discussions of NMR spectra see ref. [6b,d].

[10] The following 2-aminopyrylium salts **4**[9] have been isolated (yield): X = Cl: **4a** (64%), **4b** (75%), **4c** (84%), **4d** (63%), **4e** (82%), **4f** (69%); X = Br: **4a** (47%); X = I: **4a** (49%); X = BF_4: **4b** (99%). The follwing 2-aminopyrylium salts **4** have been identified in solution[9] (NMR yields based on pyrazine as a reference): **4b** (X = OAc, 90%), **4b** (X = F, 81%), **4g** (X = $OCOCl_3$, BF_4, ca. 40%).

[11] Similarly, 2,4-bis(dialkylamino)pyrylium salts are relatively stable towards nucleophiles: R. Spitzner, R. Radeglia, W. Schroth, *Tetrahedron Lett.* **1985**, *26*, 3967–3970.

[12] A. Niederhauser, G. Bart, M. Neuenschwander, *Helv. Chim. Acta* **1973**, *56*, 2427–2449.

[13] It should be noted that the energy of **7** is supposed to increase due to the contribution of the "antiaromatic" 4π resonance form **7B**, whereas the contribution of the "aromatic" 6π resonance form **4B** is thought to lower the energy of **4**.

[14] The term "pentadienal rearrangement" goes back to Roedig, who showed that perchloropentadienals are subject to a 1,5-O-shift at high temperatures: a) A. Roedig, G. Märkl, S. Schödel, *Angew. Chem.* **1957**, *69*, 240; *Liebigs. Ann. Chem.* **1962**, *659*, 1–16. b) A. Roedig, G. Märkl, F. Frank, R. Kohlhaupt, M. Schlosser, *Chem. Ber.* **1967**, *100*, 2730–2741.

[15] Alternatively, the reactivity of pyrylium salts **4** may be increased by replacing dialkylamino groups by weaker π donors: Thus, 5-ethoxypent-2-en-4-in-1-al is available by Pd^0-induced coupling of 1-trimethylstannyl-2-ethoxyethyne with 3-iodopropenal (60%) and adds HCl to give 5-chloro-5-ethoxypenta-2,4-dien-1-al. After storage of a solution of this compound in $CDCl_3$ for 30 days at $-30\,^\circ C$, ethyl 5-chloropentadienoate is isolated in 50% yield: C. Bacilieri, Diplomarbeit, Universität Bern, **1995**.

[16] Apparently, E_3N may induce a ring opening by nucleophilic attack at C(6) of **4b** [**4b** (X = OAc)→→**6b** (X = Et_3N^+)], so that even weak nucleophiles such as AcO^- may displace Et_3N in an addition–elimination sequence. It seems that Et_3N is an attractive nucleophilic auxiliary for inducing ring openings of easily available 2-aminopyrylium salts of type **4** (X = Cl, OAc). Experiments in view of generalizing this method are planned.

[17] a) W. Flitsch, B. Müter, U. Wolf, *Chem. Ber.* **1973**, *106*, 1993–2000; b) W. Flitsch, F. Kappenberg, H. Schmitt, *ibid.* **1978**, *111*, 2407–2422.