Pyridazine ring opening in phthalazines induced by electron transfer

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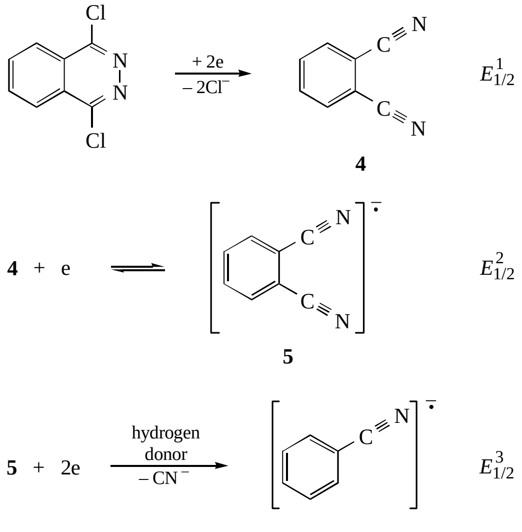
The formation of phthalonitrile from 1-Cl-4-X-phthalazines possessing a substituent capable of anionic elimination in the 4-position (X = Cl, OPh or OMe) was found to be induced by electron transfer.

The processes of electron transfer to halogen-containing organic molecules, in particular, compounds containing the C(Cl)=N group (imidoyl halides, α-halogenated aza cycles, *etc.*), as a rule, result in the rupture of the C–Hal bond.[1,2] The substitution of hydrogen for the halogen atom is the most frequent case, but other reactions can take place depending on the nature of the compound. Thus, electron transfer to the molecules of benzoyl chloride arylhydrazones was accompanied by the cleavage of both the C–Cl bond and the N–N bond with the formation of benzonitrile and the corresponding amines.[3] We assumed that this electrochemical reduction of heterocyclic compounds can result in heterocyclic ring opening. In this connection, we have studied the electrochemical reduction of 1,4-dichlorophthalazine **1**[2] in more detail and of 1-chloro-4-RO-phthalazines [R = Ph (**2**) or Me (**3**)] for the first time. Voltammetry and electrolysis–EPR in DMF in the presence of 0.1 M Bu_4NI were used.

The polarograms of 1,4-dichlorophtalazine **1** in DMF and of compounds **2**, **3** exhibit three or two waves of reduction, respectively. Table 1 summarises the polarography data. The first wave of compound **1** is irreversible (Figure 1), and its limiting current corresponds to the transfer of two electrons per molecule. At the potentials of the second one-electron wave and the third two-electron wave, intermediates oxidised in the same potential range were detected by commutative polarography. The concentrations of the intermediates were no high as judged from the relative anodic currents (Table 1). The reversibility of the second stage was also confirmed by cyclic voltammetry (CV) (Figure 1). At potentials of the second waves, the electrolysis was accompanied by the formation of a paramagnetic product [$a_{H(6,7)}$ 0.417, a_N 0.173 and $a_{H(5,7)}$ 0.42 mT] detected directly in the cell of the EPR spectrometer and unambiguously identified as the phthalonitrile radical anion.[7]

The formation of the phthalonitrile radical anion during the electrochemical reduction of compound **1** indicates that, in aprotic media, the electron transfer to the molecule of 1,4-dichlorophthalazine induces a new reaction, which was not described earlier in the literature, involving the anionic elimination of chloride ions, the cleavage of the pyridazine ring and the formation of phthalonitrile **4** (Scheme 1). The overall process involves the transfer of two electrons, the cleavage of three σ-bonds (two C–Cl bonds and an N–N bond) and the formation of two new π-bonds. The diffusion nature of the limiting current of the first wave (the i_p–$v^{1/2}$ relationship is linear) indicates that all stages proceed rapidly. The subsequent two waves, the characteristics of which are identical to our data and the published data for phthalonitrile,[7] correspond to the further reduction to phthalonitrile radical anions at the potentials of the second wave and to benzonitrile radical anions at the potentials of the third wave. It is the benzonitrile radical anions, detected by EPR [$a_{H(2,6)}$ 0.363, a_N 0.215, $a_{H(3,5)}$ 0.03 and $a_{H(4)}$ 0.842 mT], that result in the appearance of the anodic current in the commutative curves at the potentials of the third wave. The low values of the anodic oxidation current of the phthalonitrile and benzonitrile radical anions are explained by the consumption of the radical anions in the homogeneous reduction of initial compound **1**. The overall five-electron transfer of the reduction of 1,4-dichlorophthalazine can be represented by Scheme 1.



Scheme 1

The electrochemical reduction of 1-Cl-4-RO-phthalazines **2**, **3** proceeds according to a similar scheme. In this case, the corresponding anodic currents were also observed in the voltammograms (Figure 1) and in the commutative curves. The phthalonitrile and benzonitrile radical anions were detected by EPR during electrolysis at the potentials of the first and second waves, respectively.

The potentials $E_{1/2}$ of the first wave of the reduction of 1-Cl-4-X-phthalazines **1**, **3** increased with increasing electron-donor properties of the X group (Table 1). Compound **1** is reduced more easily than phthalonitrile; therefore, in this case, the separate reduction of the above compounds was observed. Compounds **2** and **3** are reduced in the same potential range as phthalonitrile; because of this, only a three-electron wave of reduction was detected.

It is well known that the radical anions of organic compounds are effective electron-transfer agents in the processes of reduction of halogen-containing organic compounds. The potential differences of the reduction of phthalonitrile and compounds **1**–**3** are

Table 1 The characteristics of the reduction waves of substituted phthalazines **1**–**3** and phthalonitrile **4** in DMF in the presence of 0.1 M Bu_4NI.

Compound[a]	mp/°C[b]	$-E^c_{1/2}$/V	$\Delta E[\Delta \lg i/(i_d - i)]^{-1}$/mV	n^d	i_a/i^e_c
1	163–164	0.93	63	2.0	0.0
		1.14	58	1.0	0.59
		2.05	128	2.4	0.41
2	120–122	1.07	52	3.0	0.24
		2.02	125	2.4	0.18
3	105–108	1.16	68	3.0	0.24
		2.03	115	2.4	0.18
4	138–140	1.12[f]	60	1.0	0.78
		2.03	130	2.0	0.60

[a]Phthalazines **1** and **3** were synthesised according to the known procedures.[4,5] [b]Boutius heat apparatus; Lit., mp/°C: **1**, 164;[4] **3**, 108;[5] **4**, 139–141.[6] [c]At a Hg electrode *vs.* Hg/I⁻. [d]The number of electrons determined by comparison with the one-electron wave of the benzophenone reduction. [e]The ratio of the anodic commutative current to the cathodic current for reversible processes under the given conditions (*f* = 10 Hz) is equal 0.78. [f]Data from ref. 6.

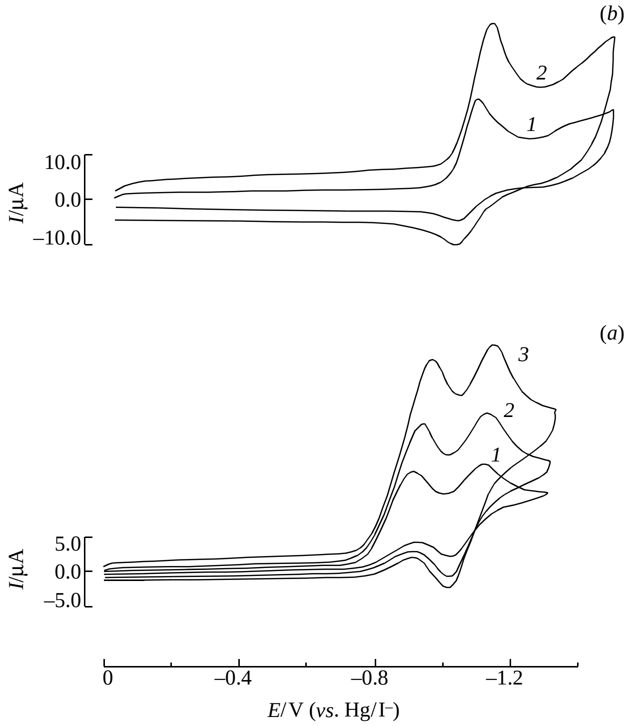
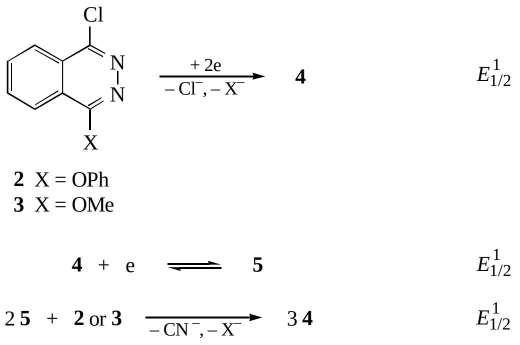


Figure 1 Cyclic voltammograms of (*a*) 1,4-dichlorophthalazine and (*b*) 1-chloro-4-methoxyphthalazine ($c = 1\times10^{-3}$ mol dm^{-3}) in 0.1 M Bu_4NI–DMF at a glassy carbon electrode for the potential sweep rates υ = (*1*) 20, (*2*) 50 and (*3*) 100 mV s^{-1}; T = 25 °C.

very low or even have a negative value. This is indicative of a high rate of homogeneous reduction of the initial compounds by the phthalonitrile radical anions generated at the electrode. The appearance of low concentrations of these radical anions leads to, on the one hand, a dramatic increase in the contribution of the homogeneous reaction to the overall reduction process and, on the other, an increase in the overall rate of reduction. In fact, an autocatalysis phenomenon takes place. This can affect the slope and the wave symmetry, as we have observed in the case of compounds **2**, **3** (Table 1). The slope for compound **2** is somewhat lower (52 mV at 25 °C), and the wave for compound **3** is much steeper in the initial portion.

Thus, the simultaneous heterogeneous and homogeneous reduction of compounds **2** and **3** according to Scheme 2 takes place during the electrochemical reduction.

The one-electron level of the limiting current of the second wave for 1,4-dichlorophthalazine, which corresponds to the reduction of phthalonitrile, and the three-electron level of that for compounds **2** and **3** indicate that in DMF pyridazine ring opening in



Scheme 2

the phthalazine system proceeds quantitatively with the formation of phthalonitrile under conditions of voltammetry. This conclusion was indirectly confirmed by EPR spectroscopy: for all of the compounds under identical conditions, signals of the phthalonitrile radical anion with almost equal intensities were observed.

Thus, we found that pyridazine ring opening in phthalazines is the main reaction path in the electrochemical reduction in aprotic media for not only 1,4-dichlorophthalazine but also other 1,4-disubstituted phthalazines having two groups capable of anionic elimination. This reaction is specific not only for the electrochemical reduction but also for chemical reduction of the above compounds by potassium metal in DMF. In the latter case, the phthalonitrile radical anions were also detected by EPR.

References

1 L. G. Feoktistov, in *Organicheskaya elektrokhimiya* (*Organic Electrochemistry*), eds. M. M. Baiser and H. Lund, Moscow, Khimiya, 1988, p. 270 (in Russian).

2 V. Kh. Ivanova, B. I. Buzykin and N. N. Bystrykh, *Khim. Geterotsikl. Soedin.*, 1979, 541 [*Chem. Heterocycl. Compd.* (*Engl. Transl.*), 1979, 443].

3 L. A. Taran, B. I. Buzykin, O. Yu. Mironova, N. G. Gasetdinova and Yu. P. Kitaev, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1983, 166 (*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1983, **32**, 142).

4 J. Druey and B. H. Ringer, *Helv. Chim. Acta*, 1951, **34**, 197.

5 F. M. Rowe and A. T. Peters, *J. Chem. Soc.*, 1933, 1331.

6 C. K. Mann and K. K. Barnes, *Electrochemical Reactions in Nonaqueous Systems*, Marcel Dekker, New York, 1970, 338.

7 P. H. Rieger, J. Bernal, W. H. Reinmuth and G. K. Fraenkel, *J. Am. Chem. Soc.*, 1963, **85**, 683.

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