Electrochemical Properties of Pyrido[1',2':1,2]imidazo[4,5-b]pyrazine and Pyrido[1',2':1,2]imidazo[4,5-b]quinoxaline Derivatives

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The peak potentials (Ep) of 3-substituted pyrido[1',2':1,2]imidazo[4,5-b]pyrazine and pyrido[1',2':1,2]-imidazo[4,5-b]quinoxaline derivatives are sufficiently correlated with Hammett substituent constant σ_m and with the PM3 calculated LUMO energy levels, and the linear relationship between electron potentials of 9-substituted pyridoimidazoquinoxalines and the LUMO energy levels is also found out.

Previously we reported the synthesis of pyrido-[1',2':1,2]imidazo[4,5-b]pyrazine (1) and pyrido-[1',2':1,2]imidazo[4,5-b]quinoxaline derivatives 2-5 [1-5]. Both derivatives have very strong fluorescent properties [6], which could be applied to photo-function chemistry. For example, 1 having crown ethers are applied to the cation and anion recognizing logic hosts, where the fluorescence of the pyridoimidazopyrazine serves as the output signal [7]. Electroluminescence of these derivatives is an alternative property to be disclosed for the construction of the sophisticated molecular devices. In connection with this electroluminescence, the investigation of the electrochemical properties of these derivatives is of considerable interest [8]. In this paper, we wish to report the relationship between the redox potentials of these derivatives and their substituents.
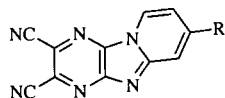
1a: R = t-Bu, 1b: R = Me, 1c: R = H,
1d: R = Ph, 1e: R = CO₂Me
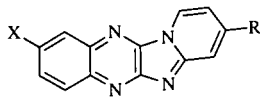
2: X = NO₂ (a: R = H, b: R = Ph, c: R = Me)
3: X = CF₃ (a: R = H, b: R = Ph, c: R = Me)
4: X = Cl, R = H
5: X = R = H

Chart 1

The pyridoimidazopyrazines 1 used and pyridoimidazoquinoxalines 2, 3b, 3c, 4, and 5 were prepared by the previously reported methods [1-4]. 9-(Trifluoromethyl)-pyridoimidazoquinoxaline 3a was also prepared by a procedure similar to the reported method [1]. Redox potential was measured by cyclic voltammetry. The reversible redox reactions were detected in all measured compounds and their peak potentials of one electron oxidation (Ep) are summarized in Tables 1 and 2.

Table 1

Redox Potentials, σ Values, and LUMO Energy Levels of
Pyridoimidazopyrazines 1

Compounds	Ep/V	σ_m of R	σ_p of R	LUMO energy level/eV
1a	-1.25	-0.100	-0.197	-1.830
1b	-1.23	-0.069	-0.170	-1.863
1c	-1.16	0.000	0.000	-1.897
1d	-1.12	0.060	-0.010	-1.969
1e	-0.90	0.390	0.385	-2.220

Table 2

Redox Potentials and LUMO Energy Levels of
Pyridoimidazoquinoxalines 2-5

Compounds	Ep/V	LUMO energy level/eV
2a	-1.13	-2.113
2b	-1.09	-2.129
2c	-1.18	-2.074
3a	-1.37	-1.873
3b	-1.23	-1.914
3c	-1.48	-1.834
4	-1.44	-1.613
5	-1.56	-1.494

There seems to be some relationships between the peak potentials (Ep) of 3-substituted pyridoimidazopyrazines and their substituent effects [9]. Really their peak potentials are successfully correlated with Hammett substituent constants σ_m, their value of correlation coefficient being sufficiently high, r = 0.9975, as shown in Figure 1. It should be noted that the peak potentials are better correlated with σ_p (r = 0.9928).

Although explanation of good relationship between peak potentials and σ_m, compared with σ_p, is a difficult problem, we propose an assumption that σ_m is directly correlated with the energy levels of lowest unoccupied molecular orbitals (LUMO) of pyridoimidazopyrazines, since redox potentials are known to depend on the energy levels of the frontier molecular orbitals. For example, redox potentials of the benzenediols were reported to be correlated with the energy levels of highest occupied molecular orbitals (HOMO) calculated by the CNDO/2 method [10]. On the other hand, it is reported that semiempirical calculation methods, particularly the PM3

method, provide a convenient tool in predicting the acidity of aromatic compounds and, for example, the calculated heats of formation and net atomic charges of the substituted phenols, anilines, and benzoic acids are successfully correlated with Hammett and Taft substituent constants [11]. Relationship of the LUMO energy levels of pyridoimidazopyrazines, calculated by PM3 method [12], with Hammett substituent constants σ_m and σ_p is shown in Figure 2. As was anticipated, σ_m was found to be better correlated with the LUMO energy levels (r = 0.9977) than σ_p (r = 0.9781). As a result, the peak potentials, Ep, of pyridoimidazopyrazines are expected to correlate with corresponding PM3 calculated LUMO energy levels, their satisfactory relationship (r = 0.9951) being depicted in Figure 3. Here the calculated LUMO energy levels are those valued without consideration of the solvent effects.
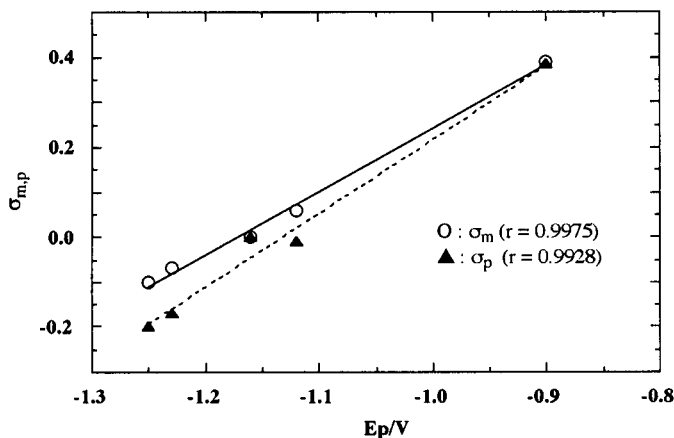

Figure 3. Plot of Ep *vs* LUMO Energy Level for Pyridoimidazopyrazines 1

number of 3-substituted 9-(nitro)- and 9-(trifluoromethyl)-pyridoimidazoquinoxalines is limited because of synthetic difficulty, their peak potentials are fully correlated with the LUMO energy levels and again with σ_m of 3-substituents, as shown in Figure 4. The slope, corresponding to ρ value in the Hammett equation, of 9-(nitro)pyridoimidazoquinoxalines 2 is steeper than that of 9-(trifluoromethyl)pyridoimidazoquinoxalines 3 and this may be ascribed to the lower lying LUMO level of 9-(nitro)pyridoimidazoquinoxaline, compared with that of 9-(trifluoromethyl)pyridoimidazoquinoxaline, which allows a larger perturbation with the 3-substituent of pyridoimidazoquinoxaline ring [13].

The effects of 9-substituents of pyridoimidazoquinoxalines were next evaluated. In this case, the significant relationship between electron potentials and Hammett substituent constants was not appreciable and, however, the calculated LUMO energy levels are better correlated with electron potentials (r = 0.971), as described in Figure 5.

Figure 1. Plot of Ep *vs* $\sigma_{m,p}$ for Pyridoimidazopyrazines 1
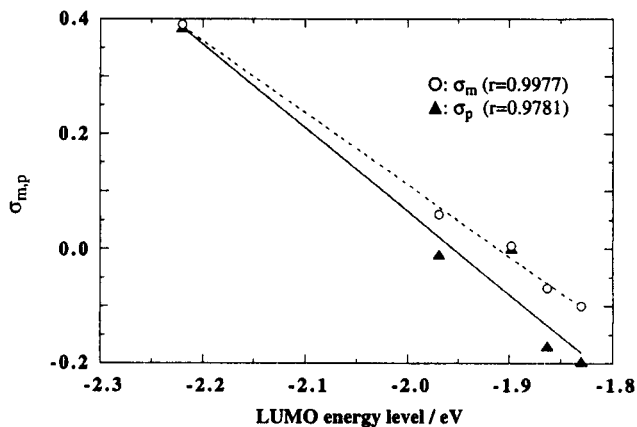

Figure 2. Plot of LUMO Energy Level *vs* $\sigma_{m,p}$ for Pyridoimidazopyrazines 1

The similar linear relationship between electron potentials and the PM3 calculated LUMO energy levels is found in the pyridoimidazoquinoxaline system. Although sampling
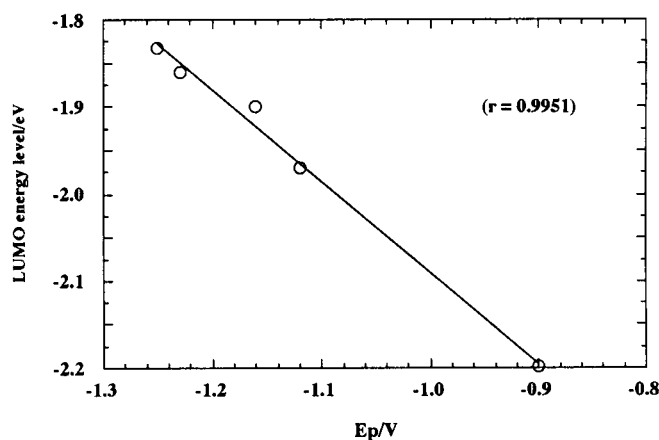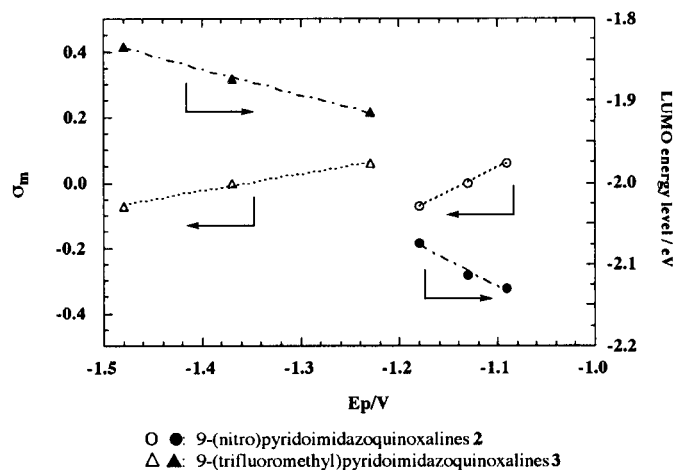

O ●: 9-(nitro)pyridoimidazoquinoxalines 2
Δ ▲: 9-(trifluoromethyl)pyridoimidazoquinoxalines 3

Figure 4. Plot of Ep *vs* LUMO Energy Level and σ_m for Pyridoimidazoquinoxalines 2 and 3
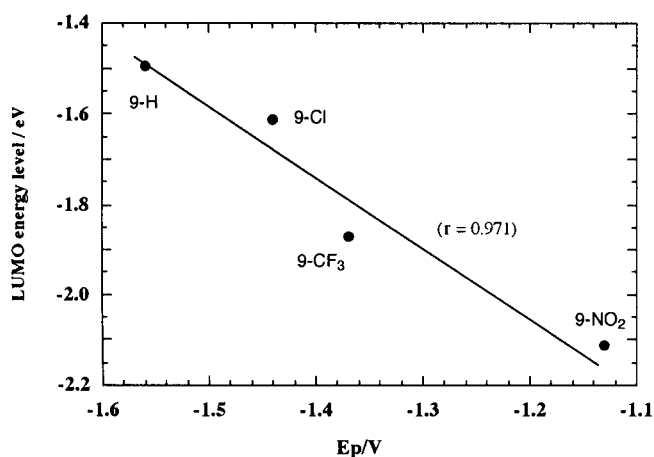
Figure 5. Plot of Ep *vs* LUMO Energy Level for 9-Substituted Pyridoimidazoquinoxalines

In conclusion, the peak electron potentials of 3-substituted pyridoimidazopyrazines and pyridoimidazoquinoxalines are sufficiently correlated with the Hammett substituent constant σ_m and with the PM3 calculated LUMO energy levels and, moreover, the linear relationship between electron potentials of 9-substituted pyridoimidazoquinoxalines and their LUMO energy levels is also determined. These results suggest the possibility that the peak electron potentials of pyridoimidazopyrazines and pyridoimidazoquinoxalines are predicted by the PM3 calculations.

EXPERIMENTAL

The ir spectra were recorded on a JASCO Report-100 spectrophotometer and samples were run as potassium bromide pellets. The ^{1}H-nmr spectra were taken on a JEOL JNM-GX270 (270 MHz) spectrometer by using tetramethylsilane as an internal standard. The chemical shifts (δ) are reported in deuteriochloroform.

The redox potentials were measured with Hokuto Denko HAB-151 potentio-galvanostat. A platinum working electrode, platinumwire counter electrode, and Ag /Ag$^+$ reference electrode were employed. The sample (0.1 m*M*) was dissolved in *N,N*-dimethylformamide containing tetrabutylammonium perchlorate (0.1*M*), and electrical potential was swept at the rate of 200mV/sec.

9-(Trifluoromethyl)pyrido[1',2':1,2]imidazo[4,5-*b*]quinoxaline (3a).

2-Amino-3-chloro-6-(trifluoromethyl)quinoxaline (0.50 g, 2.0 mmoles) [1] was allowed to react with pyridine (0.79 g, 10.0 mmoles) in dimethylformamide (5 ml) at 100 ° for 24 hours. After cooling the reaction mixture, the resulting precipitate was filtered and washed with hot water and ether. The precipitate was recrystallized from ethyl acetate to give 0.40 g (70%) of 3a as fine yellow plates, mp 268.5-269.5 °; ^{1}H-nmr: δ= 7.09(1H, ddd, J = 7.1 , 6.3 and 1.5 Hz), 7.77-7.85 (2H, m), 7.95 (1H, dd, J = 9.0 and 2.0 Hz), 8.39 (1H, d, J = 9.0 Hz), 8.68 (1H, d, J = 2.0 Hz), 8.93 (1H, dd, J =7.1 and 1.5 Hz); ir: 1120 cm^{-1} (CF$_3$).

Anal. Calcd for $C_{14}H_7N_4F_3$: C, 58.34; H, 2.45; N, 19.44. Found: C, 58.07; H, 2.23; N, 19.16.

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