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CHARGE TRANSFER INTERACTION OF 4-NITROPYRIDINE- AND 4-NITROQUINOLINE-N-OXIDES

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The π-π type charge transfer (CT) interaction ability of 4-nitropyridine- and 4-nitroquinoline-N-oxides was examined. It is concluded that the latter compound is a slightly stronger π electron acceptor than the former, and that the strength of these N-oxides as π type electron acceptor is relatively weak compared to that of the other typical electron acceptors such as p-benzoquinone etc.

It is well known that whereas 4-nitroquinoline N-oxide (4NQO) is a potent carcinogen 4-nitropyridine N-oxide (4NPO) has no such activity.[1] As one important reason for this difference in biological activity, the stronger molecular interaction ability of 4NQO has been pointed out.[2] 4NPO and 4NQO have two functional groups in their molecules: an NO_2 group showing a strong electron attracting nature, and an $\overset{+}{\text{N}}\rightarrow\overset{-}{\text{O}}$ group which acts in two ways, both electron attracting from and electron donating to the ring conjugate system.[3] The above electronic circumstances of these molecules would seem render them favorable as electron acceptors for π-π type charge transfer (CT) interaction, although the intramolecular electron donating character of the N-oxide group may in some degree reduce the electron accepting power. We wish to report here on the π-π interaction ability of 4NQO and 4NPO, investigated by means of the electronic spectra of the compounds.

As typical π electron donors we used tetramethyl-p-phenylene diamine (TMPD), dimethyl aniline (DMA), hydroquinone (HQ), HQ dimethyl ether (HQDE), hexamethyl benzene (HMB), durene, and mesitylene. Since the equilibrium constant is quite small, it was necessary to use relatively high concentrations of donors: C_D^o = 0.1-0.6 mol/l for acceptor concentration $C_A^o \approx 10^{-2}$ mol/l. These conditions limit the suitable solvents to CH_3CN and CH_2Cl_2, the latter being used only for alkyl benzene donors. Spectral measurement was made in the visible region. Fig. 1 shows the spectral change of 4NPO on addition of certain electron donors.

With increasing donor ability the end absorption in the visible region of 4NPO and 4NQO clearly shifts to longer wavelength. An absorption maximum seems to appear in the visible region with TMPD complexes of 4NPO and 4NQO (see Figs 1 and 2). The spectral changes are generally in a longer wavelength region with 4NQO than with 4NPO as acceptor. It may be noted that the N-oxide spectra should be blue shifted by hydrogen bonding interaction because of the well known blue shift phenomenon of aromatic N-oxide compounds, including 4NPO and 4NQO, in protic

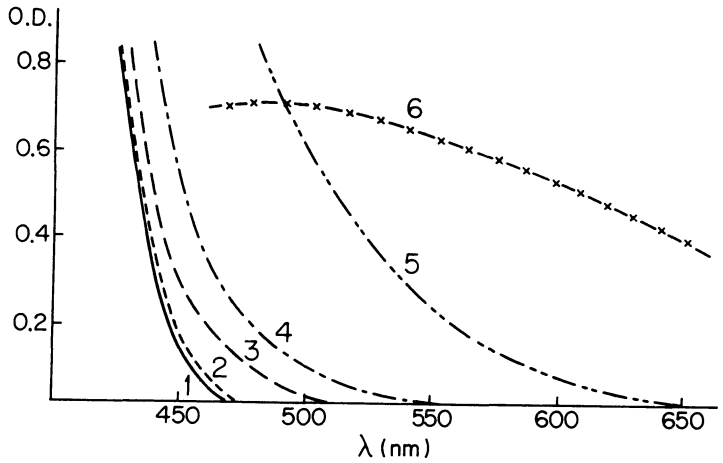

Fig. 1. Absorption spectra in the visible region of 4NPO complexes with some π electron donors in CH_3CN or CH_2Cl_2 (for curve 2 only) at 21-22°C. The concentrations of 4NPO and the donors are 0.01 mol/l and 0.3 mol/l, respectively, and are constant. Cell length: 5 cm. Curves 1, 2, 3, 4, 5, and 6 are for 4NPO alone (1), 4NPO complexes with mesitylene (2), HQDE (3), HQ (4), DMA (5), and TMPD (6). The ordinate for curve 6 is 2/5 reduced in scale.

solvents, where hydrogen bonding interaction plays an important role.[4] This phenomenon was not observed with the spectral measurement in the visible region for the case of HQ-4NPO and 4NQO complexes, so that π-π type complex formation would seem to be responsible for the spectral change in the visible region. Nevertheless, in spite of high concentration of donor molecules the spectral change in Fig. 1 is not large compared to that observed in the visible region for usual π-π type CT complexes. The change in intensity upon donor addition was well expressed assuming 1:1 complex formation, application of equation (1) being suitable under the present experimental conditions.[5] Here, K, ℓ, and D_{AD} are equilibrium constant (1/mol), cell length, and optical density due to complex AD, respectively.

$$\frac{C_A^o\, C_D^o}{D_{AD}(C_A^o + C_D^o)} = \frac{1}{K\varepsilon_{AD}\cdot\ell}\cdot\frac{1}{(C_A^o + C_D^o)} + \frac{1}{\varepsilon_{AD}\cdot\ell} \qquad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

Eq. 1 was quite well satisfied, but the values K and ε_{AD} could not be separated accurately from the linear plotting, as is often the case with small K values.[3,4] Various trials for separating K and ε values, however, indicated roughly that the K value may be less than 1 even for the TMPD complexes of 4NPO and 4NQO. The Kε values as a function of wavelength for 4NQO complexes with several donors are given in Fig. 2. Note that the stronger is the donor, the larger is the red shift of the absorption spectrum, and that the Kε value seems not to be large even for the 4NQO (4NPO)-TMPD system. For the TMPD complexes with 4NPO and 4NQO the heat of formation (ΔH) was determined from the temperature dependence of the Kε value assuming ε to have no temperature dependence and using the equation R ln Kε =

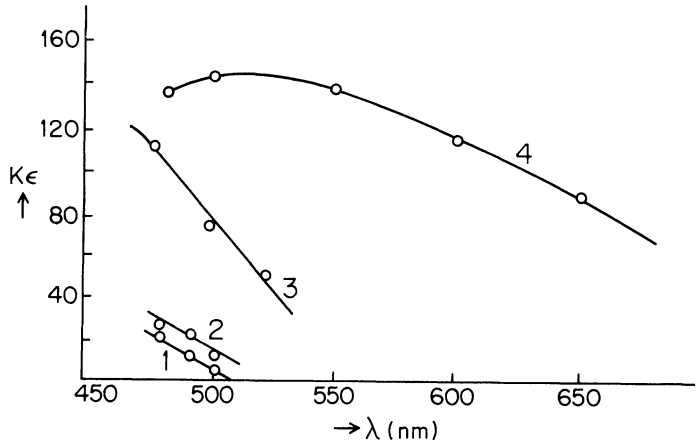

Fig. 2. The wavelength dependence of Kε values obtained in CH_3CN at 21-22°C. Curves 1, 2, 3, and 4 are for 4NQO complexes with HQDE (1), HQ (2), DMA (3), and TMPD (4).

$-\Delta H(1/T) + \Delta S + R \ln \varepsilon$. Good linear relation was obtained for the plot of R ln Kε vs. 1/T. The ΔH values are: -1.3 ± 0.3 kcal/mol and -1.6 ± 0.2 kcal/mol for 4NPO and 4NQO complexes with TMPD in CH_3CN solvent, respectively. These data show the π-π type CT interaction ability of 4NQO to be almost the same as or slightly stronger than that of 4NPO by taking into account the experimental accuracy. Based on the experimental results mentioned hitherto, 4NPO and 4NQO can form 1:1 type π-π CT complexes, but the complexing ability of the N-oxides seems relatively weak as is understood from the ΔH and Kε values and from the degree of color change with the complex formation. It is noted that the ε value (oscillator strength f) of the CT absorption band is a good measure of the stability of CT complexes.[3,4]

The Kε and ΔH values obtained here for the 4NPO and 4NQO-TMPD systems are almost the same as those for the p-benzoquinone-HQDE system.[6] Since TMPD is a stronger π donor than HQDE, 4NPO and 4NQO would be a weaker acceptor than p-benzoquinone. The intramolecular CT from the N-oxide group oxygen atom to the ring system and to the NO_2 group may be a main reason for the weak electron accepting power of 4NPO and 4NQO, because this effect would make the electron density in the ring system more or less rich.

We next tried to obtain the molecular complexes studied here in crystalline state, but were successful only with the HQ complexes with 4NPO and 4NQO.[7] The compositions of the crystals are: 4NPO(2)-HQ(1) (mp 128-130°C, orange) and 4NQO (2)-HQ(1) (mp 134-135°C, deep orange). Here, it is noticed that the N-oxide group oxygen atom in 4NPO and 4NQO is capable of participating in hydrogen bonding CT interaction,[4] and that the hydrogen bonding ability of the nitro group oxygen atoms in the molecules is much weaker than that of the N-oxide group.[8] The HQ has two phenol type OH groups in the molecule, whose hydrogen bonding ability is relatively large.[4,9] Because the π-π complexing ability of 4NPO and 4NQO is not high as has been mentioned hitherto, it is predicted that in the crystals of HQ-4NPO and 4NQO complexes the hydrogen bonding interaction between the N-oxide group and the OH group plays an important role. Assuming that the two

OH groups in the HQ molecule would form hydrogen bond individually with an N-oxide group oxygen atom in 4NPO or 4NQO, the aforementioned compositions of the crystals are also well understood. It is now interesting to check experimentally whether or not the molecular arrangement in the above crystals is of the π-π sandwich type or an n-σ type CT hydrogen bonding complex. The molecular and the crystal structures investigated by X-ray analysis will be reported in the following letter.

In earlier reports[2] the molecular interaction studies of 4NPO and 4NQO were carried out in protic medium with such biologically interested substances as deoxyribonucleosides etc. In these systems the nature of molecular interactions seems not to be simple. There may occur simultaneous participation of various kinds of CT interactions[3,4] such as n-σ, n-π, π-π, and hydrogen bonding interactions.[1,2] However, as far as the π-π type interaction in ideal systems is considered, the complexing ability of 4NPO and 4NQO is weak as studied here. Thus it may be inferred that if the stronger molecular complexing ability of 4NQO than 4NPO is essentially important for the biological activity of 4NQO, the molecular interactions other than the π-π type play also an important role. More detailed molecular interaction studies as well as the effects of molecular size and reactivity are hoped to make the biological activity of N-oxides clear.

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