Crystal Structures of Palladium(II) Ternary Complexes of 5-X-2-Aminobenzoic Acid with 1,10-Phenanthroline and Their Interaction with Calf Thymus DNA (Where X=Cl, Br and I)

Yue WANG,[a] Nobuo OKABE,*[,b] and Mamiko ODOKO[b]

[a] *Laboratory of Inorganic Chemistry, China Pharmaceutical University; Nanjing 210009, China: and* [b] *Faculty of Pharmaceutical Sciences, Kinki University; 3–4–1 Kowakae, Higashiosaka, Osaka 577–8502, Japan.*

Received May 30, 2005; accepted June 30, 2005

The crystal structures of a series of three palladium(II) ternary complexes of 5-halogeno-2-aminobenzoic acid (5-X-AB, where X=Cl, Br and I) with 1,10-phenanthroline [Pd(5-Cl-AB)(phen)] (1), [Pd(5-Br-AB)(phen)] (2) and [Pd(5-I-AB)(phen)] (3) have been determined, and their coordination geometries and the crystal architecture characterized. All of the complexes are an isostructure in which each Pd(II) atom has basically similar square planar coordination geometry. The substitute halogen group at 5-position of AB plays an important role in producing the coordination bonds of the carboxylate and amino groups in which the carboxylate O atom and the amino N atom act as the negative monodentate ligand atoms. The coordination bond distances of O–Pd increase in the order 1<2<3, while those of N–Pd decrease in the same order. The binding of the complexes to the calf thymus DNA has also been studied by the fluorescence method. Each of the complexes shows high binding propensity to DNA which can be reflected as the relative order 1<2<3.

Key words palladium(II) complex; crystal structure; 5-hallogeno-2-aminobenzoic acid; 1,10-phenanthroline; DNA binding

Antitumor Pt(II) drugs like cisplatin or carboplatin have serious side effects of nephrotoxicity, gastrointestinal toxicity, oxotoxicity or neurotoxicity. Numerous Pd(II) or Pt(II) complexes have been synthesized and evaluated to overcome these drawbacks or to develop alternative active agents with equivalent or greater antitumor activity. Pd(II) complexes have been studied extensively as prototypes for Pt(II) complexes. Especially, one Pd(II) complex [Pd(bpy)(CBDCA)] (bpy=2,2′-bipyridine, CBDCA=1,1-cyclobutanedicarboxylate) is demonstrated to have better cytotoxic activity than cisplatin against P388 lymphocytic leukaemia cells.[1)] Work in our laboratory has focused on studies of the synthesis and coordination chemistry of the Pd(II) complexes with various biologically relevant ligands and heterocyclic ligands. We have studied a series of bischelate square-planar complexes of the type [Pd(N–N)(O–N′)] or [Pd(N–N)(O–O)], where N–N is 1,10-phenranthroline (phen), 2,2′-bipyridine (bipy) or 2,2′-bipyridineamine (bpa), and O–N′ or O–O′ is the second bidentated ligand.[2—5)]

The interactions of benzoic and halogenobenzoic acids with metal ions are commonly studied in relation to environmental, antimicrobial and medical problems. But only a few structures of metal halogenobenzoates have been found, *e.g.*, tetrakis(μ2-*o*-chlorobenzoato-*O*,*O′*)-bis(aqua-copper(II)),[6)] tetra-aqua-bis(*m*-chlorobenzoato-*O*)-nickel(II)[7)] and diaqua-bis (*p*-chlorobenzoato)-zinc(II)[8)] were reported. However no crystal structures have yet been investigated for the effect of halogen group on the metal complex of halogenoaminobenzoate. For these reasons, we performed a systematic study of the coordination chemistry of the Pd(II) ternary complexes of the 5-halogenoderivatives of the biologically important 2-aminobenzoic acid, (anthranilic acid; Vitamin L_1), [Pd(5-X-AB)(phen)] (where X=Cl, Br, I, AB=2-aminobenzoic acid): synthesis of the complexes, characterization of the crystal structures, and evaluation of the binding propensity to calf thymus DNA.

Experimental

Materials The analytical grade reagents of 1,10-phenanthroline, palladium(II) acetate, 5-X-2-aminobenzoic acid (5-X-AB; X=Cl, Br, I), ethidium bromide (EB), calf thymus (CT) DNA and *N*,*N′*-dimethylformamide (DMF) were obtained from Wako Pure Chemical Industries, Ltd. (Osaka, Japan). Fluorescence measurements were performed with a Hitachi 850 spectrofluorometer equipped with a temperature control bath. All spectroscopic measurements were performed at 25 °C. Element analysis was done by using YANACO CHN Coder MT-3.

Preparation of the Single Crystals of Complexes All single crystals of the complexes were prepared at 1 : 1 : 2 molar ratio of the metal, phen and the AB ligands. The typical synthesis is described below:

Two mg (0.011 mmol) phen was mixed with 2.5 mg palladium(II) acetate (0.011 mmol) in 5 ml DMF solvent for about 15 min. Then 3.9 mg (0.022 mmol) 5-Cl-AB, 4.8 mg (0.022 mmol) 5-Br-AB, and 5.8 mg (0.022 mmol) 5-I-AB were respectively added to the mixture and reacted for no less than 30 min. The dark red solution was placed at room temperature and kept for slow evaporation. Ten days later dark red platelet-like crystals suitable for X-ray diffraction studies were obtained from the mother liquor.

$[Pd(5\text{-}Cl\text{-}AB)(phen)]_2\cdot 2H_2O$: *Anal.* Calcd for $[Pd(5\text{-}Cl\text{-}AB)(phen)]_2\cdot 2H_2O$: C, 48.008; H, 3.058; N, 8.823. Found: C, 48.129; H, 2.976; N, 8.864.

$[Pd(5\text{-}Br\text{-}AB)(phen)]_2\cdot 2H_2O$: *Anal.* Calcd for $[Pd(5\text{-}Br\text{-}AB)(phen)]_2\cdot 2H_2O$: C, 43.999; H, 2.721; N, 8.104. Found: C, 44.085; H, 2.652; N, 8.253.

$[Pd(5\text{-}I\text{-}AB)(phen)]_2\cdot 2H_2O$: *Anal.* Calcd for $[Pd(5\text{-}I\text{-}AB)(phen)]_2\cdot 2H_2O$: C, 38.056; H, 2.336; N, 7.105. Found: C, 37.967; H, 2.348; N, 6.993.

X-Ray Crystal Analysis The X-ray measurements were made on a Rigaku RAXIS RAPID diffractometer with a graphite monochromatised Mo$K\alpha$ radiation (λ=0.71069 Å) using ω scan mode at the low temperature of 123 K. A summary of the crystallographic data and structure refinements is given in Table 1. The data were corrected for Lorentz and polarization effects. The structure was solved by direct methods[9)] using the Crystal Structure[10)] software package, and refinement was performed using SHELXL-97.[11)] All H atoms including water molecules were located from difference Fourier maps and treated as riding, with C–H distance of 0.93, amine N–H distance of 0.86, U_{iso}(H) values equal to 1.2 U_{eq}(C) and U_{iso}(water H) values equal to 1.5 U_{eq}(C) (U_{eq} is the equivalent isotropic displacement parameter for the pivot atom). The two water molecules of complex **2** and **3** were disordered and their water O atoms were calculated to have an occupancy value of 0.325 and 0.675 for one and 0.405 and 0.595 for the other in **2**, as well as the value of 0.40 and 0.60 for one and 0.47 and 0.53 for the other in **3**. The water H atoms for **2** and **3** could not be located.

The function of $\Sigma w(F_o^2-F_c^2)^2$ was minimized by using the weight scheme of $w=1/[\sigma^2(F_o^2)+(aP)^2+bP]$, where $P=(F_o^2+2F_c^2)/3$. Final R [$=\Sigma(|F_o|-|F_c|)/\Sigma|F_o|$], Rw [$=(\Sigma w(|F_o|-|F_c|)^2/\Sigma w|F_o|^2)^{1/2}$] and S (goodness of fit)

* To whom correspondence should be addressed. e-mail: okabe@phar.kindai.ac.jp

Table 1. Crystal Data and Structure Refinement for Complex **1**—**3**

	1	**2**	**3**
Formula	$(C_{19}H_{12}ClN_3O_2Pd)_2\cdot 2H_2O$	$(C_{19}H_{12}BrN_3O_2Pd)_2\cdot 2H_2O$	$(C_{19}H_{12}IN_3O_2Pd)_2\cdot 2H_2O$
Formula weight	948.42	1037.32	1131.27
Crystal system	Triclinic	Triclinic	Triclinic
Space group	P-1	P-1	P-1
a (Å)	9.494(9)	9.50(1)	9.557(7)
b (Å)	12.00(1)	11.98(1)	11.78(1)
c (Å)	16.39(2)	16.73(2)	17.18(1)
α (°)	90.61(4)	87.77(4)	91.97(3)
β (°)	89.04(4)	88.56(5)	92.15(3)
γ (°)	113.93(3)	66.19(5)	112.43(3)
V (Å^3)	1707(3)	1741(3)	1784(2)
Z	2	2	2
D_{calc} (g/cm^{-3})	1.845	1.980	2.099
T (K)	123.1	123.1	123.1
F (000)	944	1008	1080
Crystal size (mm)	0.20×0.10×0.05	0.25×0.10×0.02	0.25×0.15×0.05
Absorption coefficient (mm^{-1})	1.270	3.387	2.796
Reflection measured/unique	11330/7666	17136/7999	16407/8183
Observed reflections	3846	4808	5393
$R(F^2>2s-(F^2))$	0.0520	0.0526	0.0356
$wR(F^2)$	0.1470	0.1428	0.0948
Goodness of fit	0.897	1.000	1.071
no. of variables	488	506	506

Table 2. Bond Distances (Å) and Angles (°) for Complex **1**—**3**

$(C_{19}H_{12}XN_3O_2Pd)_2\cdot 2H_2O$	Bond distances		Bond angles	
Complex **1** (X=Cl)	Pd1–O11: 1.960(4)	Pd2–O21: 1.979(4)	O11–Pd1–N11: 169.9(2)	O21–Pd2–N21: 171.0(3)
	Pd1–N11: 2.022(4)	Pd2–N21: 2.026(5)	N12–Pd1–N13: 175.9(2)	N22–Pd2–N23: 178.7(2)
	Pd1–N12: 2.024(6)	Pd2–N22: 2.021(7)	O11–Pd1–N12: 88.5(2)	O21–Pd2–N22: 89.5(2)
	Pd1–N13: 1.949(6)	Pd2–N23: 1.944(7)	O11–Pd1–N13: 92.6(2)	O21–Pd2–N23: 91.6(2)
Complex **2** (X=Br)	Pd1–O11: 1.973(4)	Pd2–O21: 1.969(4)	O11–Pd1–N11: 169.6(2)	O21–Pd2–N21: 171.12(19)
	Pd1–N11: 2.023(5)	Pd2–N21: 2.025(5)	N12–Pd1–N13: 175.76(19)	N22–Pd2–N23: 178.9(2)
	Pd1–N12: 2.031(6)	Pd2–N22: 2.026(6)	O11–Pd1–N12: 89.04(19)	O21–Pd2–N22: 89.4(2)
	Pd1–N13: 1.935(6)	Pd2–N23: 1.948(6)	O11–Pd1–N13: 92.1(2)	O21–Pd2–N23: 91.7(2)
Complex **3** (X=I)	Pd1–O11: 1.976(3)	Pd2–O21: 1.978(4)	O11–Pd1–N11: 170.3(2)	O21–Pd2–N21:171.51(16)
	Pd1–N11: 2.026(4)	Pd2–N21: 2.026(4)	N12–Pd1–N13: 175.9(2)	N22–Pd2–N23: 178.31(19)
	Pd1–N12: 2.014(5)	Pd2–N22: 2.024(5)	O11–Pd1–N12: 89.4(2)	O21–Pd2–N22: 90.27(17)
	Pd1–N13: 1.942(5)	Pd2–N23: 1.940(4)	O11–Pd1–N13: 92.0(2)	O21–Pd2–N23: 91.21(17)

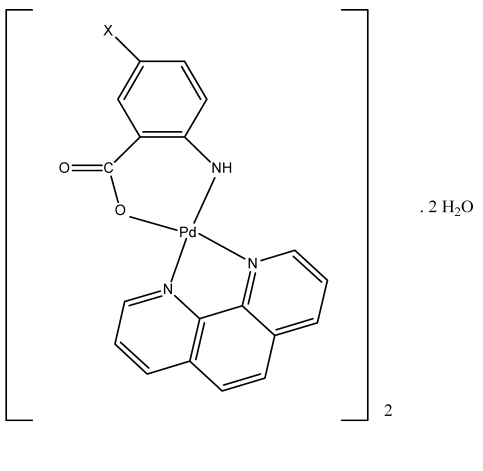
[$=(\Sigma w(|F_o|-|F_c|)^2/(M-N)^{1/2}$), where M=no. of reflections and N=no. of variables used for the refinement] are given in Table 1. Anisotropic displacement coefficients were refined for all non-hydrogen atoms.

The final anisotropic displacement coefficients, anisotropic temperature factors, bond lengths, bond angles, torsion angles of non-H atoms, and the atomic coordinates of H atoms have been deposited in the Cambridge Crystallographic Data Centre, Cambridge University Chemical Laboratory, Cambridge CB21EW, U.K. (CCDC 271628 for complex **1**, CCDC 271629 for complex **2**, CCDC 271630 for complex **3**).

Results and Discussion

Crystal Structure The complexes **1**, **2** and **3** are isostructural (triclinic, comparable cell dimensions, the same space group and similar internal atomic coordinates), and selected bond lengths and angles are summarized in Table 2. In all complexes, Pd(II) has the same square-planar coordination geometry with the formula $[Pd(phen)(5\text{-X-AB})]_2\cdot 2H_2O$ (X=Cl, Br, I in complex **1**, **2** and **3**, respectively). Hence, only the detailed structure of complex **1** is shown in Fig. 2.

The crystal structure of **1** consists of two independent Pd(II) coordination moieties. Each Pd(II) center is located in a square-planar coordination geometry which is defined by two N atoms from phen ligand, one amino N atom and one carboxylate O atom from 5-Cl-AB ligand. The square-plane is slightly distorted because the bite of N–Pd–N formed by a five-membered-chelate ring is smaller than that of N–Pd–O



X= Cl, Br, I

Fig. 1. Chemical Structures of Three Complexes, **1**—**3**

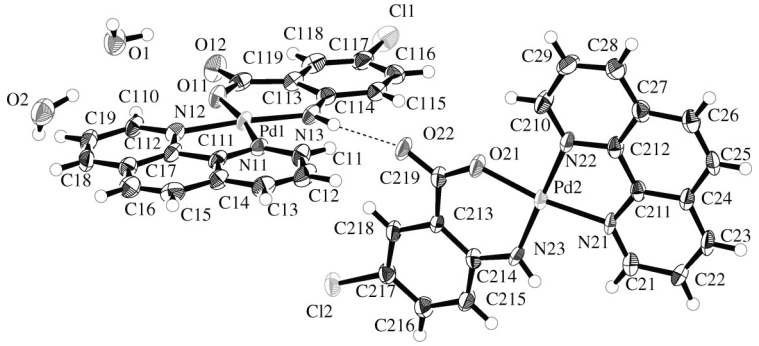


Fig. 2. ORTEPII Drawing of Complex **1**, Showing 50% Probability Displacement Ellipsoids

formed by a six-membered-chelate ring, and the Pd1(II) and Pd2(II) are slightly deviated from the corresponding plane by 0.031(2) Å and 0.011(2) Å, respectively. The 5-Cl-AB acts as a bidentate ligand to supply an amino N atom and one carboxylate O atom. Another uncoordinated carboxylate O atom participates in the intermolecular H-bond with the two hydrated water molecules (O1–H1$\cdots$O22 (symmetry code: $1-x$, $1-y$, $1-z$) 2.899(8) Å; O1–H2$\cdots$O12 2.998(7) Å; O2–H4$\cdots$O12 (symmetry code: $1-x$, $-y$, $1-z$) 2.839(8) Å). It is observed that the carboxylate group is almost coplanar with its mother benzene ring, indicated by the torsion angle of C114–C113–C119–O11 being $-0.3(9)°$. Thus, the overall complex molecule is basically planar which is indicated by the following dihedral angles of phen plane and 5-X-AB plane: 3.3(3)° for Pd1 moiety and 8.5(3)° for Pd2 moiety in **1**. Each Pd(II) moiety has the same coordination environment and they are linked by the intermolecular H-bond between the imino group of 5-Cl-AB ligand of Pd1 moiety and the carboxylate O atom of 5-Cl-AB ligand of Pd2 moiety (N13–H13$\cdots$O22 (3.120(7) Å)). The overall crystal structure of complex **1** is stabilized by two types of intermolecular π–π interactions between the phen ligands shown in Fig. 3. One exists between the phen ligands belonging to an adjacent Pd1 moiety with the interplane distance of 3.503(12) Å, and the other to an adjacent Pd2 moiety with the interplane distance of 3.342(9) Å. Similar π–π interactions are also present in complex **2** and **3**. This kind of stacking tendency is indicative of an ability to intercalate into base pairs of DNA which will be discussed in the last part of this study.

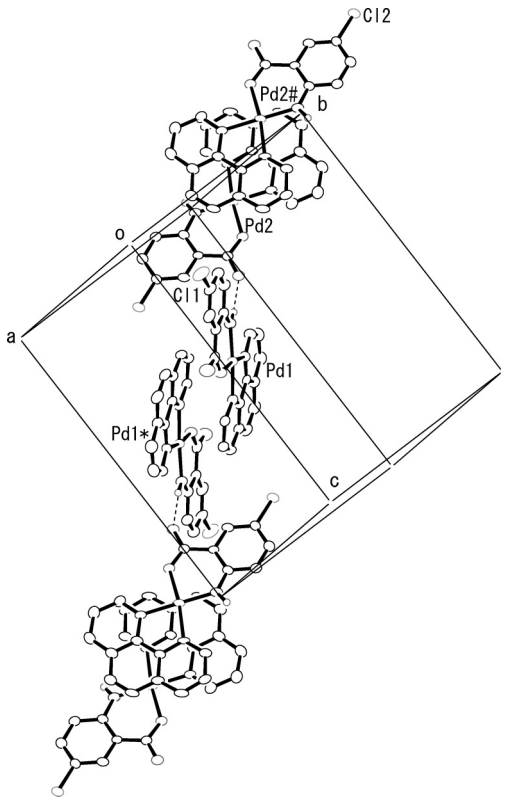


Fig. 3. A View of the Packing Pattern between the Adjacent Phen Molecules in Complex **1**, Including H-Bond Networks Indicated by Thin Lines

Symmetry code of *: $2-x$, $1-y$, $1-z$; #: $1-x$, $2-y$, $-z$.

As the remarkable common structural feature of all complexes, it should be noted that the amino N atom of 5-X-AB is involved in the coordination as the ligand atom in the deprotonated $-NH^-$ anion. The whole complex molecule thus is neutral together with action of the ionized $-COO^-$ group. The following two reasons explain this: (1) the Pd atom which decides the basic square-planar geometry with limited bite angle is based on the dsp^2 hybridization orbital, and it is inclined to bind to the *ortho*-position donors against the –COOH group. (2) The introduction of a strong electrophilic halogen group (X) on the benzene ring at 5-position influences the electron density in the aromatic ring as it increases the acidity of the electron donating $-NH_2$ group which causes NH^- anion by deprotonation. Our experiment using *ortho*-aminobenzoic acid without X substituent as ligand instead of 5-X-AB showed that no complex crystals were obtained under the same reaction conditions. Hence we deduce that the introduction of halogen substituent at the 5-position strongly influences the electron density of the benzene ring and increases the coordination activity of $-NH_2$ group. As far as we know, this kind of contribution of $-NH_2$ group as $-NH^-$ anion to the coordination bond has rarely been reported.

The basic coordination geometry is almost the same for the three complexes. The carboxylate groups in the complexes are monodentate and the halogen atoms do not participate in metal coordination. On the other hand, for the action of the substitute of X groups which have different electrophilic properties, different coordination bond distances are observed between the three complexes. The detailed comparison is summarized in Table 3. It is observed that the mean Pd–O($-COO^-$) distances of the three complexes increase and that the Pd–N($-NH^-$) distances decrease in the following sequence: **1**<**2**<**3**. It is reported that halogen substituents at

Table 3. The Comparison of Bond Distances (Å) in Complex **1—3**

5-X-AB	Mean distance of Pd–O(–COO^-)	Mean distance of Pd–N(–NH^-)
X=Cl	1.965(4) Å	1.947(6) Å
X=Br	1.971(4) Å	1.942(5) Å
X=I	1.977(4) Å	1.941(5) Å

meta-position of halogenobenzoic acid induced a decrease in electronic charge density of the carboxylate group as the result of electronic perturbation of the benzene ring in the order F<Cl<Br<I.[12] This observation is confirmed by our result that carboxylate group of complex **3** with the substituent of I atom on the ligand has the weakest coordination capability as indicated by the slightly longer Pd–O bond distance. On the other hand, the –NH^- group exhibits the reverse tendency, and the ligand with Cl atom has the weakest coordination capability with longest Pd–N distance. This reverse phenomenon may be explained by considering that the strong electrophilic halogen groups induce the decrease of the electron charge density of –NH^- group in the order Cl>Br>I. Especially, Pd–N(–NH^-) distances in this study are much shorter than the other Pd(II) complexes including the coordinated –NH_2 groups of 2.028(4)—2.045(3) Å in [$PdCl_2$(2-β-D-xylopyranose)],[13] 2.009(11)—2.019(11) Å in [Pd(en)methylmalonato] and 2.022(2)—2.030(2) Å in [Pd(en)1,1-cyclobutanedicarboxylato].[14]

The bond distances of Pd–N(phen) ranging from 2.014(5) Å to 2.031(6) Å in complex **1**, **2** and **3** are longer than those of most of the reported values in palladium complexes including phen ligand, while the Pd–O(–COO^-) distances in this study are much shorter than those in the other palladium carboxylate complexes.[4,15] In all three complexes, the order of average bond distance is Pd–N(phen)> Pd–O(–COO^-)>Pd–N(–NH^-). This means that the coordination mode in this series of complexes is not in agreement with the common fact observed in many ternary complexes: there is larger complexation strength of the phen than of the second ligand in ternary complex.[16] The order of Pd–N(phen)>Pd–N(–NH^-) may be explained as the result of –NH^- anion formation in 5-X-AB. And the short Pd–O(–COO^-) distances compared with the other palladium carboxylate complexes may also be attributable to the effect of the halogen substituents on the electronic perturbation of the benzene ring as mentioned above,[12] to which the electron density of the neighboring –NH^- group may contribute. So the –COO^- group of 5-X-AB having X substituent is electronically more negative than that without X substituent and consequently is more valuable to coordinate to the metal center.

All the complexes contain two hydrated water molecules. We were able to determine the H atoms of the two water molecules of complex **1** completely. While complex **2** and **3** have two disordered water molecules, even their crystal data are obtained at the low temperature of −150 °C. For this reason, the water H atoms for **2** and **3** are not determined, although their structures are reasonable and are in conformity with their element analysis results.

One common intermolecular X···O type charge transfer interaction involving donation of oxygen lone-pair electrons

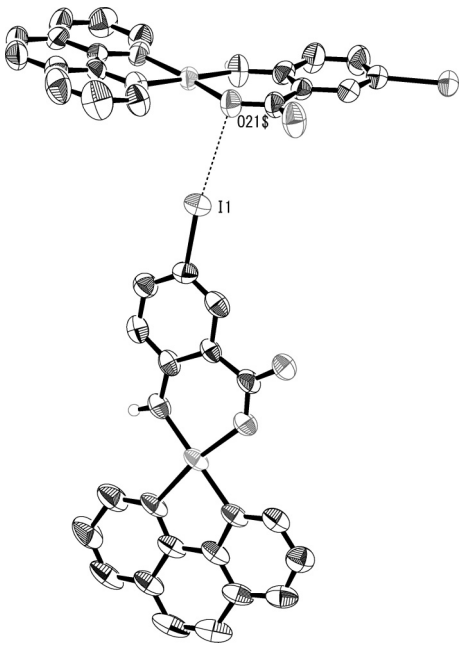


Fig. 4. Intermolecular C–I···O Contact between Symmetry Related Molecules

Symmetry code of $: $-1+x$, $-1+y$, z.

to vacant 5 d orbitals on X atom present in the three complexes as shown in Fig. 4. The X···O distances of each complex are Cl1···O21 ($-1+x$, $-1+y$, z) of 3.427(4) Å for **1**, Br1···O21 (x, $-1+y$, z) of 3.323(5) Å for **2** and I1···O21 ($1+x$, $1+y$, z) of 3.327(3) Å for **3**. Within these, I1···O21 is considerably shorter than the I···O van der Waals contact distance of 3.55 Å as compared with the others (Cl···O, 3.27 Å; Br···O, 3.37 Å). Such type of charge-transfer bond has been previously reported[17,18] with the similar short I···O=C distance. Another shorter I···O=C distance (2.94 Å) has also been observed for the crystal structure of the 1 : 1 diiodoacetylene-cyclohexane-1,4-dione adduct.[19]

Cody and Murray-Rust[20] reported an extensive survey of the Cambridge Crystallographic Data Base for compounds containing C–I bonds that have C–I···O(N, S) distances less than 3.55 Å. They found the contacts between I and the nucleophiles are such that the distances are shortest with the C–I···O(N, S) angles close to 180°. In this study, since the iodine atom is the largest and the most polarizable atom in the halogen series, complex **3** shows the most obvious intermolecular short contact compared with the C–Br···O in **2** and C–Cl···O in **1**.

DNA Binding Studies. DNA Binding Experiment The binding of the complexes to the calf thymus (CT) DNA has been studied by fluorescence method. Competitive binding studies have been made by measuring the emission of ethidium bromide (EB) bound to DNA which shows the enhanced emission intensity due to its intercalative binding to DNA.[21,22] The competitive binding of the complexes to the DNA reduces the emission intensity of EB with either a displacement of the bound EB from the bound to the free state or the bound complex quenching the emission with a reduction of the emission intensity due to fluorescence quenching of free EB.[23,24]

The concentration of the DNA used for binding experi-

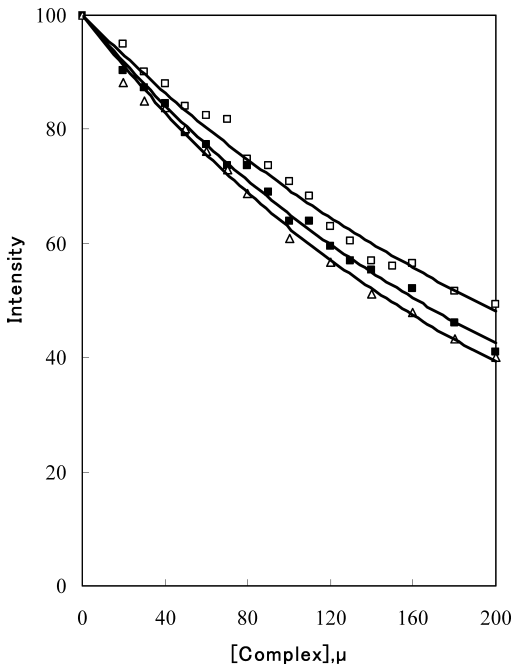


Fig. 5. The Emission Intensity of 100 μM Calf Thymus DNA-Bound Ethidium Bromide (10 μM) at Different Complex Concentrations in 50 mM Tris–HCl–50 mM NaCl Buffer (pH, 7.4) at 25 °C on Addition of Complex **1** (□), Complex **2** (■) and Complex **3** (△)

ments was determined by measuring the absorption intensity 260 nm with the molar extinction coefficient value of 6600 $M^{-1}cm^{-1}$ in 10 mM Tris–HCl–50 mM NaCl buffer (pH 7.4).[25] In a typical binding experiment, a 2 μl solution of 1.45 mM ethidium bromide (EB) was added to a volume of 300 μl of 100 μM DNA solution. All the fluorescence measurements were taken at λ_{ex} of 545 nm and λ_{em} of 600 nm at 25±0.1 °C. An aliquot of 3 mM solution of the complexes in DMF was added to the EB-DNA solution. The mixtures were incubated overnight and their fluorescence intensity was measured. The fluorescence intensities were plotted against the complex concentration to get a slope that gave the relative extent of binding of the complexes to DNA. A control experiment was also done with the EB in the absence of DNA. The apparent binding constant (K_{app}) values for the complexes were estimated from the equation: K_{EB}[EB]=K_{app}[Complex] using the K_{app} value of EB as 10^7 M^{-1}.[26,27]

DNA Binding Results Figure 5 shows the decreasing propensity in the emission intensity of the EB on addition of the complexes into the DNA solution. All complexes show high binding propensity to DNA. Combining the very near relative extent of binding of the complexes to DNA indicated by the near slopes in the plots shown in Fig. 5 with their similar overall size and coplanar shape of the complex molecules, we demonstrate that the intercalation of complex molecules between nucleobases may be the major driving force leading to binding. This result coincides with their common π–π stacking interactions between the phen ligands mentioned above, because usually intercalators stack in their solid state lattices.[28]

It is still observed that EB bound DNA was a little more quenched by complex **3**, in which the displacement process of EB occurred. The values of the apparent binding constant (K_{app}) deduced from the slope of the quenching plot with the complex concentration are 5.2×10^5 M^{-1}, 6.0×10^5 M^{-1} and 6.6×10^5 M^{-1} for **1**, **2** and **3**, respectively, which can be arranged as the relative order: [Pd(5-Cl-AB)(phen)] **1**<[Pd(5-Br-AB)(phen)] **2**<[Pd(5-I-AB)(phen)] **3**. This may be related to the above mentioned short I···O contact distance causing the I···O type interaction between [Pd(5-I-AB)(phen)] and guanine or thymine bases which contain O=C bonds. This is supported by the fact that the iodine atom plays an important role as an essential component of thyroid hormones in a biological system, and the interactions between the oxygen and iodine atoms have been observed in the complexes of transthyretin with thyroxine[29] and 3,3′-diiodo-thyronine.[30] Another likely force governing the highest tendency of [Pd(5-I-AB)(phen)] intercalated into DNA is dipole–dipole interaction between the planar, polarizable ring of the complex due to high polarizability of the iodine atom and the nucleobases. These considerations will be proved by further studies.

References

1) Mansuri-Torshizi H., Ghadimy S., Akbarzadeh N., *Chem. Pharm. Bull.*, **49**, 1517—1520 (2001).
2) Wang Y., Okabe N., *Chem. Pharm. Bull.*, **53**, 366—373 (2005).
3) Wang Y., Mizubayashi Y., Odoko M., Okabe N., *Acta Cryst.*, **C61**, m67—70 (2005).
4) Musunori Y., Okabe N., *Acta Cryst.*, **C60**, m47—50 (2004).
5) Okabe N., Hagihara K., Odoko M., Muranishi Y., *Acta Cryst.*, **C60**, m150—152 (2004).
6) Kawata T., Ohba S., Tokii T., Muto Y., Kato M., *Acta Cryst.*, **C48**, 1590—1594 (1992).
7) Pavkovic S. F., Wilhelm F. C., Brown J. N., *Acta Cryst.*, **B34**, 1337—1340 (1978).
8) Potocnak I., Dunaj-Jurco M., Cerna J., *Acta Cryst.*, **C49**, 1496—1498 (1993).
9) Altomare A., Burla M., Camalli M., Cascarano G., Giacovazzo C., Guagliardi A., Moliterni A., Polidori G., Spagna P., *J. Appl. Cryst.*, **32**, 115—119 (1999).
10) Crystal Structure Analysis Package, Rigaku and Rigaku/MSC. 9009 New Trails Dr. The Woodlands TX 77381 U.S.A. (2000—2004).
11) Sheldrick G. M., "SHELXL97," University of Göttingen, Germany, 1997.
12) Lewandowski W., Kalinowska M., Lewandowska H., *Inorg. Chim. Acta*, **358**, 2155—2166 (2005).
13) Brudzinska I., Mikata Y., Obata M., Ohtsuki C., Yano S., *Bioorg. Med. Chem. Lett.*, **14**, 2533—2536 (2004).
14) Tercero J. M., Matilla A., Sanjuan M. A., Moreno C. F., Martin J. D., Walmsley J. A., *Inorg. Chim. Acta*, **342**, 77—87 (2003).
15) Okabe N., Muranishi Y., Aziyama T., *Acta Cryst.*, **E59**, m936—938 (2004).
16) Groen J. H., de Jong B. J., Ernsting J.-M., van Leeuwen P. W. N. M., Vrieze K., Smeets W. J. J., Spek A. L., *J. Organomet. Chem.*, **573**, 3—13 (1999).
17) Sugimori T., Masuda H., Yamauchi O., *Bull. Chem. Soc. Jpn.*, **67**, 131—137 (1994).
18) Camerman N., Trotter J., *Acta Cryst.*, **18**, 203—211 (1965).
19) Groth P., Hassel O., *Acta Chem. Scand.*, **19**, 1733—1740 (1965).
20) Cody V., Murray-Rust P., *J. Mol. Struct.*, **112**, 189—199 (1984).
21) Le Pecq J. B., Paoletti C., *J. Mol. Biol.*, **27**, 87—106 (1967).
22) Waring J., *J. Mol. Biol.*, **13**, 269—282 (1965).
23) Mahadevan S., Palaniandavar M., *Inorg. Chem.*, **37**, 3927—3934 (1998).
24) Thomas A. M., Naik A. D., Nethaji M., Chakravarty A. R., *Inorg. Chim. Acta*, **357**, 2315—2323 (2004).
25) Reichman M. E., Rice S. A., Thomas C. A., Doty P., *J. Am. Chem. Soc.*, **76**, 3047—3053 (1954).
26) Dhar S., Nethaji M., Chakravarty A. R., *Dalton Trans.*, **2004**, 4180—4184 (2004).
27) Lee M., Rhodes A. L., Wyatt M. D., Forrow S., Hartley J. A., *Biochemistry*, **32**, 4237—4245 (1993).
28) Jennette K. W., Gill J. T., Sadownick J. A., Lippard S. J., *J. Am. Chem. Soc.*, **98**, 6159—6168 (1976).
29) Blake C. C. F., Oatley S. J., *Nature* (London), **268**, 115—120 (1977).
30) Wojtczak A., Luft J., Cody V., *J. Biol. Chem.*, **267**, 353—357 (1992).