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ORIGINAL ARTICLE

Charge-transfer interactions between piperidine as donor with different σ- and π-acceptors: Synthesis and spectroscopic characterization

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Abstract Charge-transfer (CT) complexes formed between piperidine (Pip) as donor with mono-iodobromide (IBr), 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ), 2,6-dichloroquinone-4-chloroimide (DCQ), and 2,6-dibromoquinone-4-chloroimide (DBQ), as acceptors have been studied spectrophotometrically. The synthesis and characterization of piperidine CT-complexes of mono-iodobromide, [(Pip)(IBr)], 2,3-dichloro-5,6-dicyano-1,4-benzoquinone, [(Pip)(DDQ)], 2,6-dichloroquinone-4-chloroimide, [(Pip)(DCQ)] and 2,6-dibromoquinone-4-chloroimide, [(Pip)(DBQ)] were described. These complexes are readily prepared from the reaction of Pip with IBr, DDQ, DCQ and DBQ within $CHCl_3$ solvent. IR, UV–Vis techniques and elemental analyses (CHN), characterize the four piperidine charge-transfer complexes. Benesi–Hildebrand and its modification methods were applied to the determination of association constant (K), molar extinction coefficient (ε).

1. Introduction

The theory of charge-transfer interactions or the molecular complexes produced between electron donor and electron acceptor ownership Mulliken's (1950, 1952) this theory has been successfully applied to many interesting studies (Breigleb, 1961) amongst them is the possible role of CT-complexes in chemical reactions (Kosower, 1965). The charge-transfer (CT) interaction has been widely recently. Charge-transfer complexes are known to take part in many chemical reactions like addition, substitution and condensation (Fla et al., 1991; Roy et al.,

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2000). These complexes have great attention for non-linear optical materials and electrical conductivities (Yakuphanoglu and Arslan, 2004a,b; Yakuphanoglu et al., 2005; Chakraborty et al., 2001). Electron donor–acceptor (EDA) interaction is also important in the field of drug-receptor binding mechanism (Korolkovas, 1998), in solar energy storage (Takahasi et al., 1993) and in surface chemistry (Andrade et al., 2000) as well as in many biological fields (Slifkin, 1971). On the other hand, the EDA reactions of certain π-acceptors have successfully utilized in pharmaceutical analysis (Abou Attia, 2000). For these wide applications extensive studies on CT-complexes of π-acceptors have been performed (Basavaiah, 2004). In the literature survey (Fukunaga and Ishida, 2003; Abdel Sayed et al., 2003; Kandile and Latif, 1988; Muralikrishna et al., 1983) reveals that little attention has been paid to thermodynamic and electronic spectral characteristic does not contain any information on structure behavior of the CT interactions of this compound (Pip) with σ- and π-acceptors.

Charge-transfer complexes of organic species are intensively studied because of their special type of interaction,

Table 1 Elemental analysis CHN and physical parameters data of the CT-complexes formed in the reaction of the Pip with IBr, DDQ, DCQ and DBQ.

Complexes (FW)	MW (g mol$^{-1)}$	C (%)		H (%)		N (%)		Physical data	
		Found	Calc.	Found	Calc.	Found	Calc.	Color	mp (°C)
[(Pip)(IBr)] ($C_5H_{11}NIBr$)	291.96	20.45	20.55	3.66	3.76	4.56	4.79	Viscous brown	< 30
[(Pip)(DDQ)] ($C_{13}H_{11}N_3Cl_2O_2$)	312.16	49.25	49.97	3.54	3.52	13.41	13.45	Viscous brown	< 30
[(Pip)(DCQ)] ($C_{11}H_{13}N_2Cl_3O$)	295.60	44.39	44.65	4.23	4.39	9.44	9.47	Viscous brown	< 30
[(Pip)(DBQ)] ($C_{11}H_{13}N_2Br_2ClO$)	384.52	34.12	34.32	3.31	3.38	3.32	3.38	Viscous brown	< 30

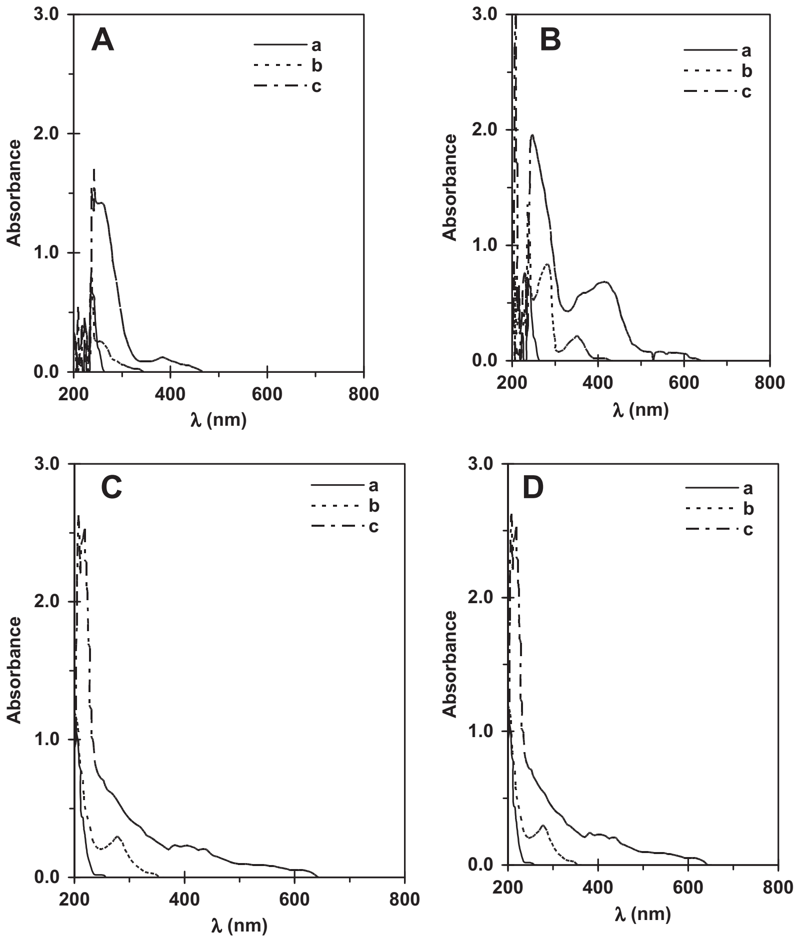


Figure 1 Electronic absorption spectra of: (A) Pip–IBr reaction in $CHCl_3$, (B) Pip–DDQ reaction in $CHCl_3$, (C) Pip–DCQ reaction in CH_3OH and (D) Pip–DBQ reaction in CH_3OH. (a) = donor (1.0×10^{-4} M), (b) = acceptor (1.0×10^{-4} M) and (c) = CT-complex.

which is accompanied by transfer of an electron from the donor to the acceptor (Das et al., 2000; Jones and Jimenez, 1999). Also, protonation of the donor from acidic acceptors are generally rout for the formation of ion pair adducts (Smith et al., 1997, 1998, 2000).

2. Materials and methods

All chemicals used throughout this work were Analar or extra pure grade. Piperidine ($C_5H_{11}N$), was of analytical reagent grade (Merck reagent). The acceptors were purchased from Aldrich. Stock solutions of piperidine or of acceptors were freshly prepared and the spectroscopic grade chloroform (Merck Co.) and methanol (BDH) were as used as received.

2.1. Preparation of piperdine-acceptor charge-transfer complexes (acceptor = IBr, DDQ, DCQ and DBQ)

2.1.1. [Piperdine]-monoidobromide complexes

The solid CT-complex of (Pip) with IBr was prepared by mixing (85.15 mg, 1.0 mmol) of the donor in chloroform (10 ml), a solution of IBr was added (206.80 mg, 1.0 mmol) in the same solvent (10 ml) with continuously stirring for about 15 min at room temperature. A dark brown solid was isolated and the solution was allowed to evaporate slowly at room temperature. A viscous oily brown complex was formed, washed several times with little amounts of chloroform, and dried under vacuum over anhydrous calcium chloride; the empirical formula of the complex [(Pip)(IBr)], is $C_5H_{11}NIBr$ with molecular weight 291.96 g/mol.

2.1.2. [Piperdine]-DDQ, DCQ and DBQ complexes

The solid CT-complexes of (Pip) with acceptors (DDQ, DCQ and DBQ) were prepared by mixing 1 mmol of the donor in chloroform (10) ml with 1 mmol of the each acceptors in the same solvent with constant stirring for about 15 min. The solutions were allowed to evaporate slowly at room temperature, the solids filtered and washed several times with little amounts of solvent, and dried under vacuum over anhydrous calcium chloride. The charge-transfer complexes [(Pip)(DDQ)] (viscous brown) formed with empirical formula as $C_{13}H_{11}N_3Cl_2O_2$ with molecular weight 312.16 g/mol, [(Pip)(DCQ)] (viscous brown) formed with empirical formula as $C_{11}H_{13}N_2Cl_3O$ with molecular weight 295.6 g/mol, [(Pip)(DBQ)] (viscous brown) formed with empirical formula as $C_{11}H_{13}N_2Br_2OCl$ with molecular weight 384.52 g/mol.

2.2. Instrumentation and physical measurements

The electronic spectra of the donors, acceptors and the resulted CT-complexes were recorded in the region of (200–800 nm) by using a Jenway 6405 Spectrophotometer with quartz cells, 1.0 cm path in length. Photometric titration were performed at 25 °C for the reactions of donors with acceptors in chloroform, as follow: the concentration of the donors in the reaction mixtures was kept fixed at 5.0×10^{-4} M, while the

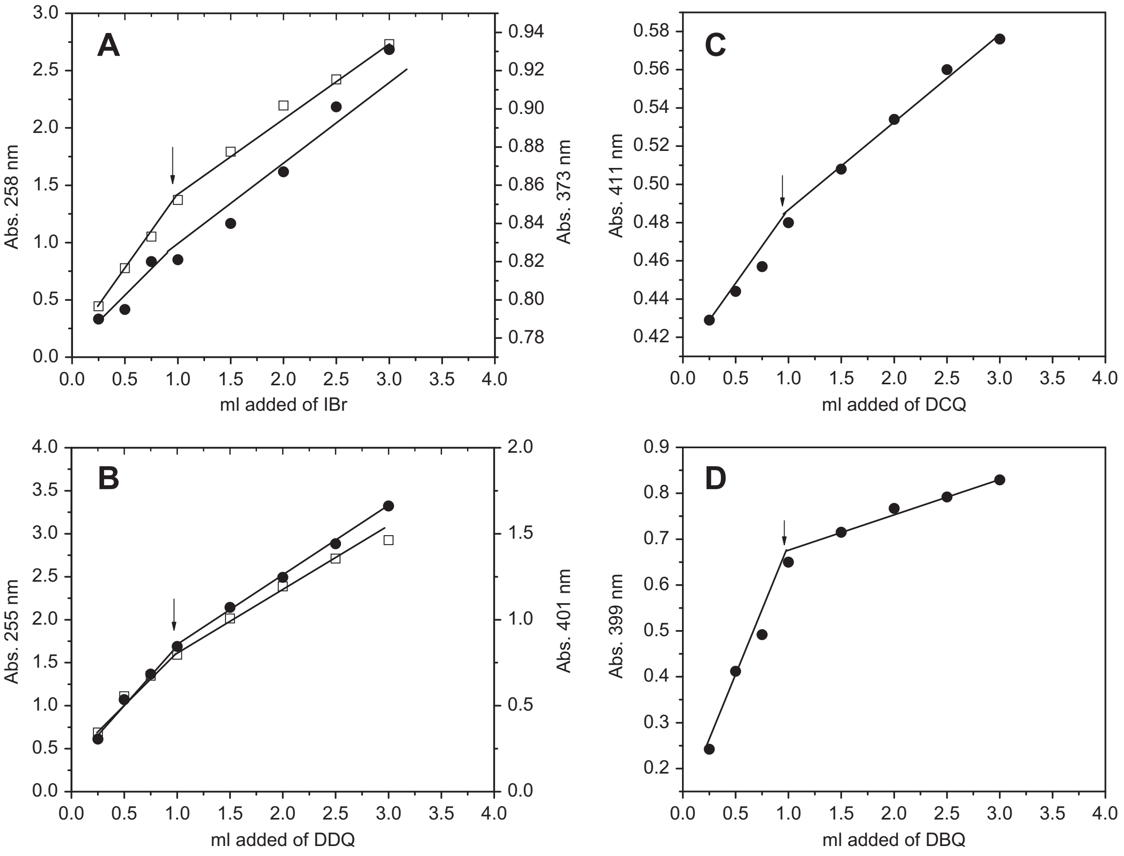


Figure 2 Photometric titration curves for: (A) Pip–IBr system in $CHCl_3$ at 258 and 373 nm, (B) Pip–DDQ system in $CHCl_3$ at 255 and 401 nm, (C) Pip–DCQ system in CH_3OH at 411 nm and (D) Pip–DBQ system in CH_3OH at 399 nm.

concentration of acceptors were changed over a wide range from $X \times 10^{-4}$ to $Y \times 10^{-4}$ M. These produced solutions with donor: acceptor molar ratios varying from 1:0.25 to 1:4.00. IR measurements (KBr discs) of the solid donors, acceptor and CT-complexes were carried out on a Bruker FT-IR spectrophotometer (400–4000 cm^{-1}).

3. Results and discussion

Piperidine (Pip) represents an interesting class of simple aromatic compounds that participated in many organic reaction mechanisms. It is particularly importantly to study the CT interaction between Pip as an electron donor with mono idodobromide (IBr) as σ-acceptor and with some π-electron acceptors such as 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ), 2,6-dichloroquinone-4-chloroimide (DCQ) and 2,6-dibromoquinone-4-chloroimide (DBQ). The elemental analysis (CHN), electronic spectra, photometric titration and mid infrared spectra were used to elucidated the nature of the interaction between donor and acceptor. The reactions of Pip with the IBr and π-acceptors were carried out in $CHCl_3$ and/or CH_3OH as a solvent. The analytical data of the solid CT-complexes (C, H, and N contents) along with some of the physical behavior data are listed in Table 1.

3.1. Electronic spectra of Pip/IBr, Pip/DDQ, Pip/DCQ and Pip/DBQ systems

The electronic spectra of the reaction mixtures containing IBr, DDQ, DCQ and DBQ with Pip as donor in $CHCl_3$ and/or CH_3OH show absorption bands located at (258 and 373 nm) for Pip/IBr, at (255, 401 and 550 nm) for Pip/DDQ, at

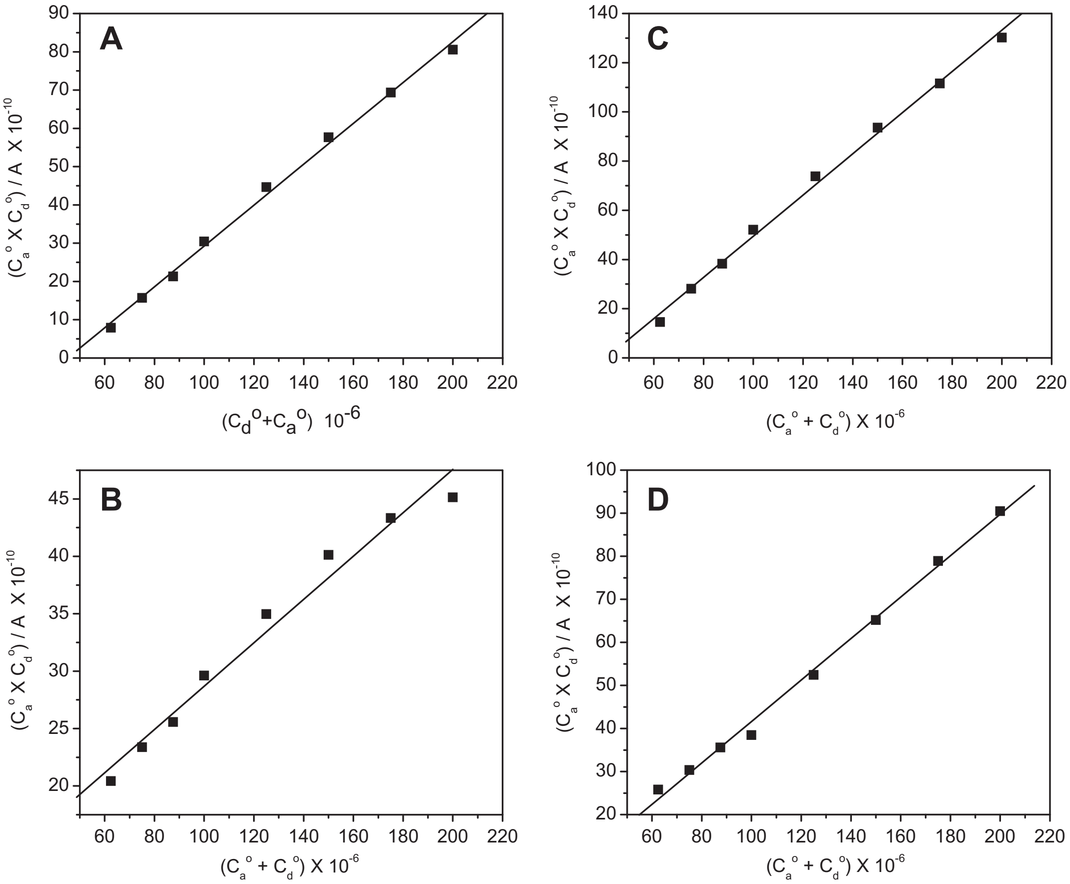


Figure 3 The plot of $(C_d^o + C_a^o)$ values against $(C_d^o \cdot C_a^o/A)$ values for: (A) Pip–IBr system in $CHCl_3$ at 373 nm, (B) Pip–DDQ system in $CHCl_3$ at 401 nm, (C) Pip–DCQ system in CH_3OH at 411 nm and (D) Pip–DBQ system in CH_3OH at 399 nm.

Table 2 Spectrophotometric results of the CT-complexes of: (A) [(Pip)(IBr)], (B) [(Pip)(DDQ)] (C) [(Pip)(DCQ)] and (D) [(Pip)(DBQ)] CT-complexes.

Complex	λ_{max} (nm)	E_{CT} (eV)	K (mol^{-1})	ε (mol^{-1} cm^{-1})	f	μ	I_p (eV)
A	373	3.33	2.48×10^4	2.01×10^4	10.90	29.30	7.44
B	401	3.10	1.41×10^4	5.93×10^4	24.60	45.80	9.55
C	411	3.03	2.67×10^4	1.25×10^4	6.14	23.10	7.23
D	399	3.12	12.43×10^4	0.45×10^4	2.03	13.10	7.30

411 nm for Pip/DCQ and 399 nm for Pip/DBQ (Fig. 1A–D). These definite absorption bands do not belong to any of the reactants and well known to be characteristic of the formation of new CT-complexes; [(Pip)(IBr)], [(Pip)(DDQ)], [(Pip)(DCQ)] and [(Pip)(DBQ)]. Photometric titrations between (Pip) and mentioned acceptors; (IBr and DDQ) in $CHCl_3$, (DCQ and DBQ) in CH_3OH based on the (258 and 373 nm) for Pip/IBr, (255 and 401 nm) for Pip/DDQ, (411 nm) for Pip/DCQ and (399 nm) for Pip/DBQ systems reveals that the stoichiometry of the reactions is 1:1 (Fig. 2A–D). This was concluded on the bases of the obtained elemental analysis data of the isolated solid CT-complexes as indicated in the Table 1, as well as from the complexes infrared spectra, which indicate the existence of the bands characteristic for both the Pip and the acceptors.

In the photometric titration measurements, the concentration of Pip was kept fixed at 1.00×10^{-4} M, while the concentration of the acceptors was varied over the range of 0.25×10^{-4}–3.00×10^{-4} M. The stoichiometry of the CT-complexes was determined by applying molar ratio method (Skoog,

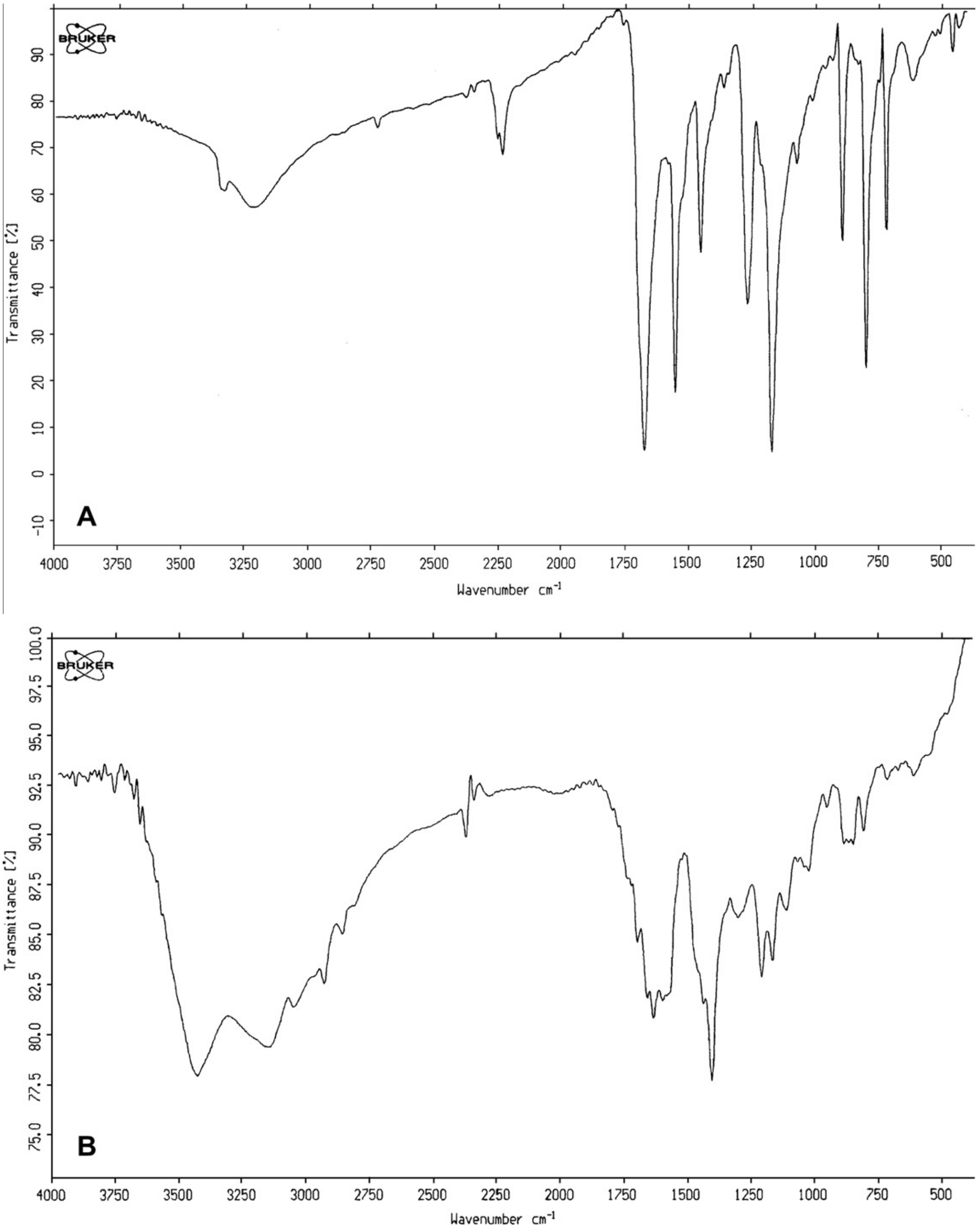


Figure 4 Infrared spectra of: (A) DDQ, (B) DCQ, (C) DBQ, (D) [(Pip)(IBr)], (E) [(Pip)(DDQ)], (F) [(Pip)(DCQ)] and (G) [(Pip)(DBQ)] complexes.

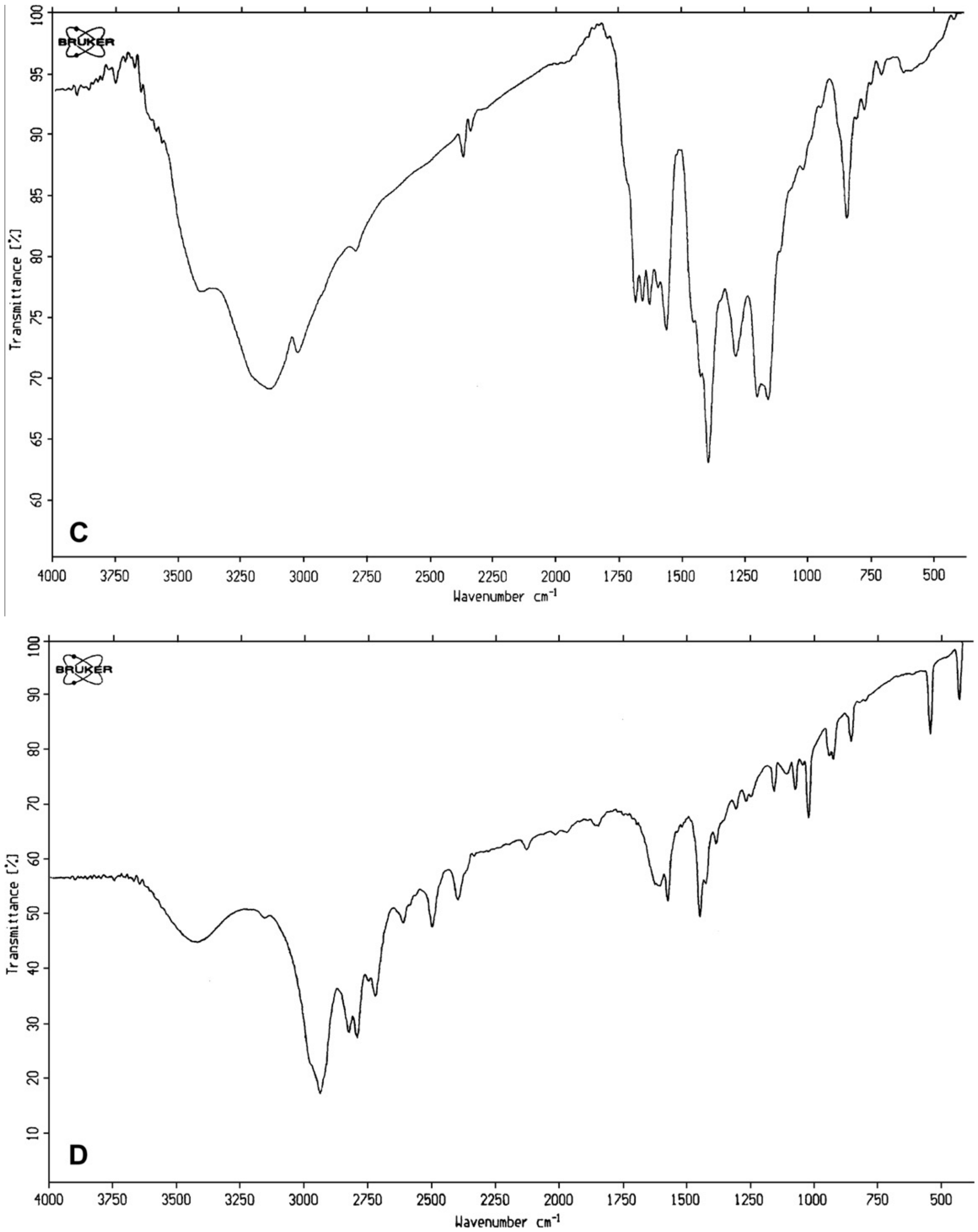


Fig. 4 (*continued*)

1985). The symmetric curves with maximum at 1.00 mol fraction indicate the formation of 1:1 CT-complexes (Fig. 2A–D). The association constant (K) values and molar extinction coefficients (ε) of the CT-complexes studies have been determined using the 1:1 modified Benesi–Hildebrand Eq. (1) Abu-Eittah and Al-Sugeir, 1976. C_a^o and C_d^o are the initial concentrations of the represented acceptors (IBr, DDQ, DCQ and DBQ) and the donor Pip, respectively, while A is the absorbance of the CT-complexation bands around 258 and 373 nm for [(Pip)(IBr)], 255 and 401 nm for [(Pip)(DDQ)], 411 nm for [(Pip)(DCQ)] and 399 nm for [(Pip)(DBQ)] complexes. Plotting the values of the ($C_a^o \cdot C_d^o/A$) against ($C_a^o + C_d^o$) values for each acceptor, a straight lines are obtained with a slope of $1/\varepsilon$ and intercept of $1/K\varepsilon$ as shown in Fig. 3(A–D), for the reaction mixtures of Pip with (IBr and DDQ) and (DCQ and DBQ) in $CHCl_3$ and CH_3OH, respectively. The values of both K and ε associated with these complexes; [(Pip)(IBr)], [(Pip)(DDQ)], [(Pip)(DCQ)] and [(Pip)(DBQ)] are given in Table 2. The oscillator strength (f) which is a dimensionless quantity used to express the transition probability of the CT band (Lever,

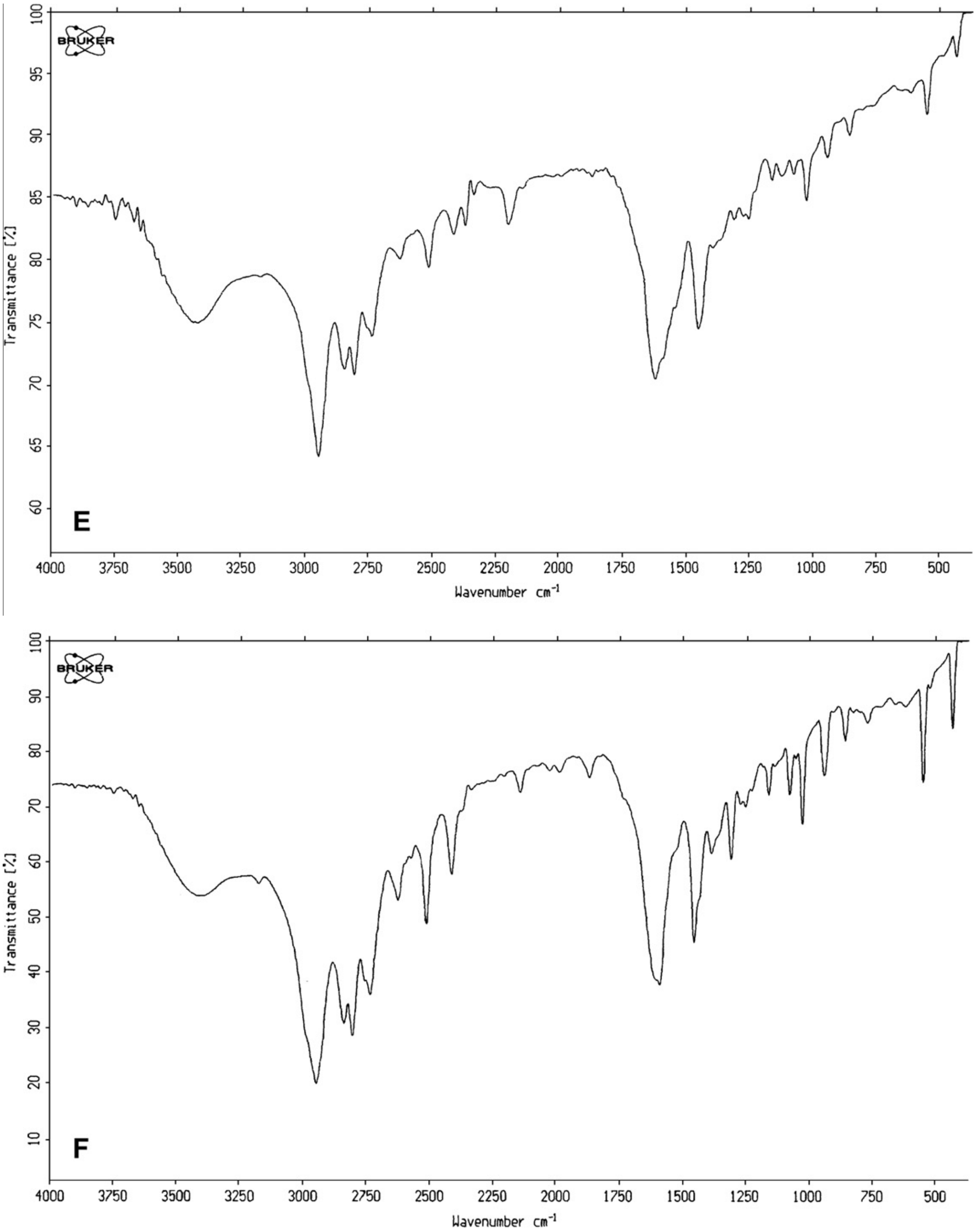


Fig. 4 (*continued*)

1985) and the transition dipole moment (μ) of the CT-complexes (Tsubomura and Lang, 1964), The high values of both the formation constant (K) and the extinction coefficients (ε) of the resulted CT-complexes back to the expected high stabilities of the formed CT-complexes as a result of the expected high donation of the Pip nucleus.

This phenomena is also strongly supported by determined the dissociation energy (W), which can be deduced from the corresponding CT energy, donor ionization potential (I_p) and electron affinity of the acceptor (DDQ, 1.95 eV; CHL, 1.37 eV; CLA, 1.10 eV) by using the following Eq. (1) McConnel et al., 1964:

$$E_{\mathrm{CT}} = I_p - E_A - W \tag{1}$$

The calculated value of (W) in the case of DDQ as acceptor is 4.50 eV. The energy of the n–π^* interaction was calculated, where λ_{CT} is the wavelength of the CT band of the complexes; 3.33 eV (IBr), 3.10 eV (DDQ), 3.03 eV (DCQ) and 3.12 eV (DBQ).

The ionization potential (I_p) of the free donor of the highest filled molecular orbital on the donor was determined from the CT energies of the CT band of its complexes with DDQ and CHL using the following Eqs. (2) and (3) Aloisi and Pignataro, 1973; Foster et al., 1969:

$$I_p\ (\mathrm{eV}) = 5.76 + 1.52 \times 10^{-4} \nu\mathrm{DDQ}\ (\mathrm{cm}^{-1}) \quad (2)$$

$$I_p\ (\mathrm{eV}) = 5.00 + 1.53 \times 10^{-4} \nu\mathrm{CHL}\ (\mathrm{cm}^{-1}) \quad (3)$$

where, ν is the wavenumber corresponding to the CT band of the CT-complexes.

The equilibrium constants are strongly dependent on the nature of the used acceptor including the type of electron withdrawing substituents to it, such as cyano and halo groups. For example, Table 2, the value of equilibrium constant for [(Pip)(IBr)] and [(Pip)(DCQ)] complexes in $CHCl_3$ and methanol, respectively, are almost the same. This value is about a twice times higher than the values of equilibrium constant for the complexes [(Pip)(DDQ)]. The [(Pip)(DBQ)] CT-complex has a five times higher than IBr/Pip and DCQ/Pip complex and so higher by nine times comparison with [(Pip)(DDQ)] charge-transfer complex.

3.2. Infrared spectra

The Infrared spectra of the 1:1 CT-complexes formed from the interaction of the donor and the respected acceptors with the general formula, [(Pip)(acceptor)], together with the corresponding free acceptor (DDQ, DCQ and DBQ) and donor Pip, are shown in Fig. 4(A–G). Full assignments concerning the all of infrared bands were located in the spectra are listed in Table 3.

A comparison of the relevant IR spectral bands of the free donor, Pip and acceptors (DDQ, DCQ and DBQ) with the corresponding appeared in the IR spectra of the isolated solid CT-complexes clearly indicated that the characteristic bands of Pip show some shift in the frequencies (Table 3), as well as some change in their bands intensities. This could be attributed

Table 3 Infrared frequencies[a] (cm^{-1}) and tentative assignments for DDQ, DCQ, DBQ, [(Pip)(IBr)], [(Pip)(DDQ)], [(Pip)(DCQ)] and [(Pip)(DBQ)] complexes.

DDQ	DCQ	DBQ	[(Pip)(acceptor)] CT-complexes				Assignments[b]
			IBr	DDQ	DCQ	DBQ	
3325 w	3424 s, br	3416 s, br	3426 s, br	3424 s, br	3401 s, br	3424 s, br	$\nu_{(\mathrm{O-H})}$; H_2O of KBr
3218 br							$\nu_{(\mathrm{N-H})}$
–	3144 s, br	3139 s, br	2948 vs	2949 vs	3177 vw	2949 vs	$\nu_{\mathrm{s(C-H)}} + \nu_{\mathrm{as(C-H)}}$
	3047 mw	3028 w	2834 w	2846 ms	2949 vs	2841 s	
	2927 mw		2803 w	2807 ms	2840 ms	2807 s	
	2855 mw		2731 w	2738 ms	2807 ms	2737 ms	
					2737 s		
–	–	–	2620 mw	2630 mw	2627 ms	2626 ms	Hydrogen bonding
			2507 ms	2517 ms	2514 s	2513 s	
			2405 ms	2417 ms	2416 s	2414 ms	
2250 vw	–	–	–	2201 ms	–	–	$\nu_{(\mathrm{C\equiv N})}$; DDQ
2231 ms							
1673 vs	1696 w	1686 w	–	1670 sh	–	1740 vw	$\nu_{(\mathrm{C=O})} + \nu_{(\mathrm{C=N})}$; DDQ, DCQ and DBQ
	1656 w	1658 w					
	1634 mw	1631 w					
–	–	–	1615 ms	1623 vs	1619 vw	1620 mw	$\delta_{\mathrm{def(N-H)}}$
							Ring breathing bands
1552 vs	1598 w	1597 vw	1582 s	1454 s	1593 vs	1584 ms	$\nu_{(\mathrm{C=C})}$; DDQ, DCQ and DBQ
1451 s	1437 sh	1564 vs	1456 s		1457 vs	1457 s	C–H deformation
1358 w	1403 vs	1398 vs	1391 vw	1313 vw	1389 mw	1390 w	$\nu_{(\mathrm{C-C})} + \nu_{(\mathrm{C-N})}$
1267 s	1300 s, br	1290 s	1313 vw	1256 w	1311 ms	1313 w	CH, in-plane bend
1172 vs	1208 s	1205 w	1273 vw	1163 w	1255 w	1256 w	
1072 w	1165 ms	1161 w	1162 ms	1125 w	1162 ms	1163 ms	
	1112 mw		1113 mw	1079 w	1080 ms	1079 w	
	1024 ms		1080 ms	1028 ms	1030 s	1029 ms	
1010 vw	953 w	848 s	1028 s	947	943 s	941 ms	δ_{rock}; NH
893 s	886 vw	778 vw	929 ms	859 mw	860 ms	860 w	CH-deformation
800 vs	849 vw	710 w	859 ms		773 w	830 vw	$\nu_{(\mathrm{C-Cl})} + \nu_{(\mathrm{C-Br})}$; DDQ, DCQ and DBQ
720 s	809 ms						
	715 w						
615 ms	611 w	622 br	549 s	617 vw	622 vw	621 vw	Skeletal vibration
527 vw				553 ms	553 s	552 s	CH bend
457 ms	451 vw	422 vw	434 s	436 ms	437 s	436 ms	CH out of plane bend
432 mw	438 vw						Skeletal vibration
							CNC def.

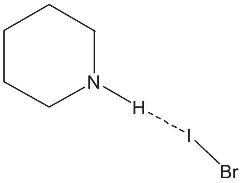
[a] s = Strong, w = weak, m = medium, sh = shoulder, v = very, br = broad.

[b] ν, Stretching; δ, bending.

to the expected symmetry and electronic structure changes upon the formation of the CT-complex. The infrared explanation will take separately for each CT-complex to give an idea about the position of complexation as follows.

3.2.1. In the case of [(Pip)(IBr)] CT-complex

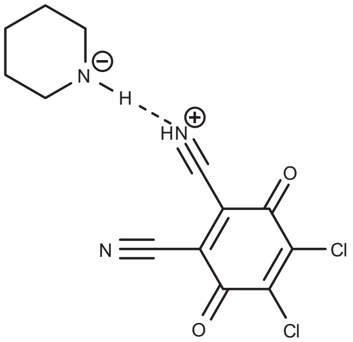
The vibration frequency of the $\nu_{(N-)}$ group for Pip observed at 3393 cm^{-1} is shifted to 3426 cm^{-1} in the IR spectrum of the CT-complex. The group of bands are exhibited at 2948, 2834, 2803 and 2731 cm^{-1} in the [(Pip)(IBr)] complex assigned to $\nu_{s(C-H)} + \nu_{as(C-H)}$ vibrations with small shift to lower wavenumbers compared with the free Pip. The spectrum of mono iodobromide/Pip complex includes a few medium strong absorption bands lying at 2620, 2507 and 2405 cm^{-1} and could be assigned to hydrogen bonding (Bellamy, 1975). Importantly, in the spectrum of [(Pip)(IBr)] complex, the vibrations group of $\delta_{(N-H)}$, $\nu_{(C-N)}$, CNC deformation show clearly changes compared with those of free Pip, Table 3. This observation proved that the complexation of (Pip) with IBr takes place via the –NH group through forming the hydrogen bonding as shown in Scheme 1.



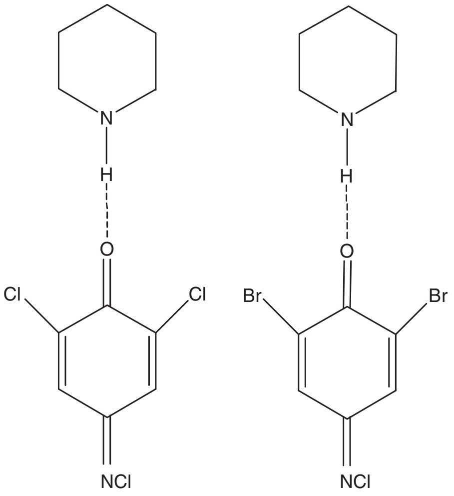
Scheme 1 Structure of the [(Pip)(IBr)] CT-complex.

3.2.2. In the case of [(Pip)(DDQ)] CT-complex

The IR spectra of the molecular complex of DDQ with Pip indicate the $\nu_{(C}\equiv$N) and $\nu_{(C-Cl)}$ of the free acceptor are shifted to lower wavenumber values on complexation. Since DDQ is deprived from any acidic centers, thus we may conclude that the molecular complexes are formed through π–π* and/or n–π* charge migration from HOMO of the donor to the LUMO of the acceptor. Also, the shift of $\nu_{(C=O)}$ of DDQ from higher to lower value on complex formation. IR spectrum of the molecular complex of DDQ with Pip indicate that the single $\nu_{(C}\equiv$N) of the free acceptor molecule which exhibited at (2250 and 2231 cm^{-1}) was shifted to a lower wavenumber value (2201 cm^{-1}) while the $\nu_{(C}$=O) absorption band of the free DDQ at 1673 cm^{-1} was shifted to lower value (1623 cm^{-1}). Careful interpretation of IR spectra strongly supported that the CT interaction in the case of Pip/DDQ complex occurs through n–π* transition deprotonation of –NH group of Pip to only one of the CN groups by forming intermolecular hydrogen bonding (Scheme 2). In addition, the characteristic bands of the hydrogen bonding are appearing in the IR spectrum of the studied complex at 2630, 2517, and 2417 cm^{-1}, this group of bands are not existed in both spectra of the free donor and acceptor.



Scheme 2 Structure of the [(Pip)(DDQ)] CT-complex.



Scheme 3 Structure of the [(Pip)(DCQ)] and [(Pip)(DBQ)] CT-complexes.

3.2.3. In the case of [(Pip)(DCQ)] and [(Pip)(DBQ)] CT-complexes

The IR spectra of the CT-complexes of DCQ and DBQ are characterized by a group of bands within the 2338–2807 cm $^{-1}$ range which are not present in the spectra of the free reactants. These bands are due to the stretching mode of a hydrogen bonding (Bellamy, 1975). This fact resulted from the hydrogen bond interaction through the proton (–NH) of Piperidine donor and the oxygen atom of the carbonyl group of acceptor. This is further strongly supported by the clearly appearance of the peaks characteristic of the $\nu_{(O-H)}$ at the wavelength 3401 and 3424 cm^{-1} for DCQ and DBQ CT-complexes, respectively. The $\nu_{(C}$=O) group appearing at 1696, 1686, 1658, 1656 and 1634 cm^{-1} are disappeared in the case of DCQ and shifted to 1620 cm^{-1} for DBQ, this led us to predicted that the carbonyl group is involvement in the complexation. The shift of the infrared characteristic bands of the acceptor moiety to lower wavenumbers and the donor moiety to higher values reflects a donor to acceptor charge-transfer transition from π to π* type, donor (HOMO)→acceptor (LOMO) Foster et al., 1969 (see Scheme 3).

References

Abdel Sayed, N.I., El Badry, K., Abdel Mohsen, H.M., 2003. J. Chin. Chem. Soc. 50 (2), 193.

Abou Attia, F.M., 2000. Farmaco 55, 659.

Abu-Eittah, R., Al-Sugeir, F., 1976. Can. J. Chem. 54, 3705.

Aloisi, G.G., Pignataro, S., 1973. J. Chem. Soc., Faraday Trans. 69, 534.

Andrade, S.M., Costa, S.M.B., Pansu, R., 2000. J. Colloid. Interf. Sci. 226, 260.

Basavaiah, K., 2004. Farmaco 59, 315.

Bellamy, L.J., 1975. The Infrared Spectra of Complex Molecules. Chapman and Hall, London.

Breigleb, G., 1961. Electron Donor–Acceptor Komplexe. Springer-Verlag, Berlin.

Chakraborty, B., Mukherjee, A.S., Seal, B.K., 2001. Spectrochim. Acta Part A 57, 223.

Das, S.K., Krishnamoorthy, G., Dofra, S.K., 2000. Can. J. Chem. 78, 191.

Fla, F.P., Palou, J., Valero, R., Hall, C.D., Speers, P., 1991. Perkin Trans. 2, 1925.

Foster, R., 1969. Organic Charge Transfer Complexes, Academic Press, London; Kinoshita, M., Bull. Chem. Soc. Jpn. 1609, 1962.

Fukunaga, T., Ishida, H., 2003. Acta Crystal. Sect. E E59 (11), 1793.

Jones, G., Jimenez, J.A.C., 1999. Tetrahed. Lett. 40, 8551.

Kandile, N.G., Latif, T.M.A., 1988. J. Chem. Soc. Pakistan 10 (3), 333.

Korolkovas, A., 1998. Essentials of Medical Chemistry, Second ed. Wiley, New York (Chapter 3).

Kosower, E.M., 1965. Prog. Phys. Org. Chem. 3, 81.

Lever, A.B.P., 1985. Inorganic Electronic Spectroscopy, Second ed. Elsevier, Amsterdam, p. 161.

McConnel, H.M., Ham, J.J., Platt, J.R., 1964. J. Chem. Phys. 21, 66.

Mulliken, R.S., 1950. J. Am. Chem. Soc. 72, 600.

Mulliken, R.S., 1952. J. Am. Chem. Soc. 74, 811.

Muralikrishna, U., Seshasayi, Y.V.S.K., Krishnamurthy, M., 1983. National Acad. Sci. Lett. (India) 6 (11), 383.

Roy, T., Dutta, K., Nayek, M.K., Mukherjee, A.K., Banerjee, M., Seal, B.K., 2000. Perkin Trans. 2, 531.

Skoog, D.A., 1985. Principle of Instrumental Analysis, third ed. Saunders College Publishing, New York, USA (Chapter 7).

Slifkin, A.M., 1971. Charge-Transfer Interaction of Biomolecules. Academic Press, New York.

Smith, G., Lynch, D.E., Byriel, K.A., Kennard, C.H.L., 1997. J. Chem. Crystallogr. 27, 307.

Smith, G., Lynch, D.E., Bott, R.C., 1998. Aust. J. Chem. 51, 159.

Smith, G., Bott, R.C., Rae, A.D., Willis, A.C., 2000. Aust. J. Chem. 53, 531.

Takahasi, K., Horino, K., Komura, T., Murata, K., 1993. Bull. Chem. Soc. Jpn. 66, 733.

Tsubomura, H., Lang, R.P., 1964. J. Am. Chem. Soc. 86, 3930.

Yakuphanoglu, F., Arslan, M., 2004a. Opt. Mater. 27, 29.

Yakuphanoglu, F., Arslan, M., 2004b. Solid State Commun. 132, 229.

Yakuphanoglu, F., Arslan, M., Kucukislamoglu, M., Zengin, M., 2005. Sol. Energy 79, 96.