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Proton transfer complexes based on some π-acceptors having acidic protons with tyramine donor: Synthesis and spectroscopic characterizations

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ABSTRACT

Charge transfer complexes based on tyramine (Ty) (4-(2-aminoethyl) phenol) organic basic donor and π -acceptors having acidic protons such as picric acid (PA), and chloroanilic acid (CA) with the compositions, [(Ty)(CA)$_2$] and [(Ty)(PA)$_2$] have been synthesized and the chemical structures were confirmed by thermal analysis and physicochemical studies such as UV visible, FT-IR and ^{1}H-NMR spectral studies. Spectroscopy measurements show that the donor–acceptor molar ratio was found to be 1: 2 for both (Ty): (PA) and (Ty): (CA) charge transfer complexes, in addition to that the $ArNH^+_3$ ammonium ion and OH^{2+} were formed under the acid–base theory through proton transfer from an acidic to basic centers in charge transfer complexes, as well as the spectroscopic data were discussed in terms of formation constant (K_{CT}) and molar extinction coefficient (ε_{CT}). Thermal behavior of both charge transfer complexes showed that the complexes were more stable than their parents.

Keywords: Charge transfer complexes, Tyramine, picric acid and chloroanilic acid.

INTRODUCTION

Nervous systems of animals use a variety of neuroactive chemicals in order to produce integrated and coordinated behaviors. Acting as neurotransmitters, neurohormones or neuromodulators these neuroactive chemicals ultimately enable flexibility in communication associated with the privacy of the message (confined to synaptic sites or accessible by many tissues as a neurohormone), speed of delivery of the message (speed of synaptic transmission or via the circulatory system as a neurohormone) and duration of the message [1, 2]. One family of neuroactive chemicals includes the biogenic amines. The classical biogenic trace amines, which include tyramine, play important roles in a variety of functions in the central nervous system. Trace amines are structurally very similar to the classical biogenic amines, and they are endogenously synthesized in neurons during the synthesis of catecholamines or monoamines [3, 4]. Trace amines have been previously considered as false transmitters that affect the storage of classical biogenic amines in synaptic vesicles via amphetamine-like mechanisms [5-7]. They also act on catecholamine transporters to potentiate the activity of other neurotransmitters [4]. However, growing body of evidence suggests that trace amines directly act on trace amine (TA) receptors to regulate the neuronal excitability in the mammalian brain [8-10]. Trace amines and TA receptors have been implicated in a variety of psychiatric disorders including schizophrenia, depression and attention deficit hyperactivity disorder [3, 7, 11 and 12]. Although more than 15 subtypes of mammalian TA receptors have been identified [13], their signal transduction pathways are largely unknown. Biogenic amines represent a small, but very important group of neuroactive chemicals derived through decarboxylation of amino acids. Two biogenic amines, the catecholamines noradrenaline and adrenaline, are predominantly important in the vertebrates, whereas another two, the monoamines tyramine and octopamine, are predominantly important in the invertebrates. Others, for example dopamine and 5-hydroxytryptamine (5-HT), are important in both vertebrates and invertebrates. Interestingly, tyramine was originally recognized as a trace amine in the vertebrate nervous system, associated with the dopaminergic system [14, 15]. In the invertebrates tyramine occurs in larger concentrations than found in the vertebrates but the vertebrate literature, was originally considered

only as a biosynthetic intermediate of octopamine and led to a reconsideration of tyramine as a true neuroactive chemical in both the vertebrates and the invertebrates [16, 17]. For example, specific tyraminergic effects on physiological processes have been described [18, 19], specific neurons have been shown to express tyramine in the absence of octopamine [20] and DNA receptor clones have been isolated from insect species and from mammals, which show specificity for tyramine [8, 21]. Thus, tyramine appears to be a legitimate neurochemical in at least the invertebrates, especially insects, where it may participate in a variety of physiologicl processes.

CT complexes have applications in many fields such as semiconductors [22], electronics, solar cells [23] optical devices and electrical conductivities [24]. Charge transfer complexes have also been recognized as an important phenomenon in drug receptor binding mechanism and in many biological processes like photosynthesis and oxidative processes [25]. The charge transfer reactions have successfully utilized in pharmaceutical analysis as given the drug (donor) with different acceptors [26]. Having the above aspects in mind and a continuation of a previous works on forming a valuable charge transfer complexes, so we have planned to target a group charge transfer complexes form tyramine as a donor a series of acceptors such that picric acid and chloranilic acid hoping to have a more valuable one.

EXPERIMENTAL SECTION

2.1. Chemical and reagents

All chemicals and reagents used in this study were of analytical grade. Picric acid and chloranilic acid were obtained from Aldrich Chemical Company.

2.2. Synthesis of charge transfer complexes of Ty donor

The two solid CT-complexes of Ty with PA and CA were prepared by mixing a saturated solution of the Ty donor in 10 ml MeOH to each of saturated solutions of CA in the same solvent and PA in the $CHCl_3$ at room temperature. The solutions were allowed to evaporate slowly at room temperature, the resulted complexes in the solid state filtered and washed several times with little amounts of solvent, and dried under vacuum over anhydrous calcium chloride. Charge-transfer complexes of Ty/ CA formed with empirical formula $C_{20}H_{15}Cl_4NO_9$ with molecular weight 555.15 g/mol and Ty/ PA formed with empirical formula $C_{20}H_{17}N_7O_{15}$ with molecular weight 595.39 g/mol, as in figure 1a and 1b respectively.

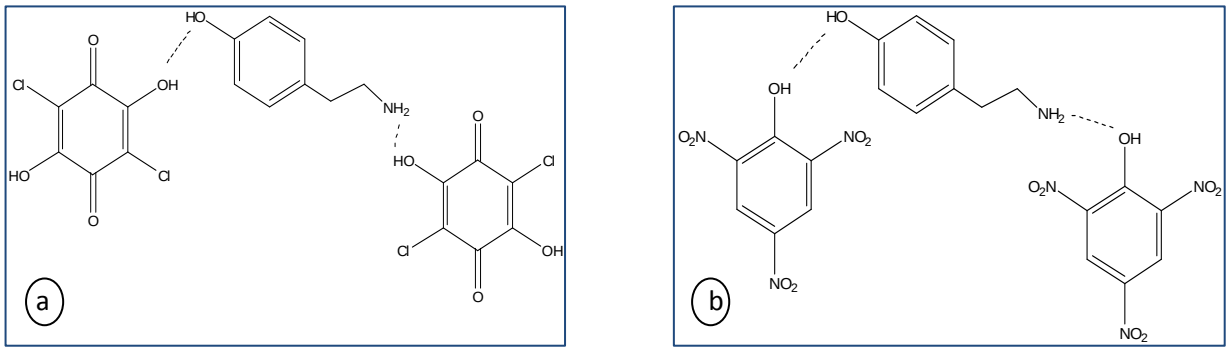


Figure1: Chemical structures of CT complexes.
[(Ty)(PA)$_2$] yellowish Color, yield:84%, [(Ty)(CA)$_2$] violet Color, yield:87%,

RESULTS AND DISCUSSION

3.1 UV- visible spectral studies.

The electronic UV- vis. spectra of the Ty, PA and its 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. IR measurements (KBr discs) of the CT complexes were carried out on a Bruker FT-IR spectrophotometer (400 –4000 cm^{-1}). The thermal analysis (TGA/ DTG) was carried under nitrogen atmosphere with a heating rate of 10 C/min using a Shimadzu TGA-50H thermal analyzers.

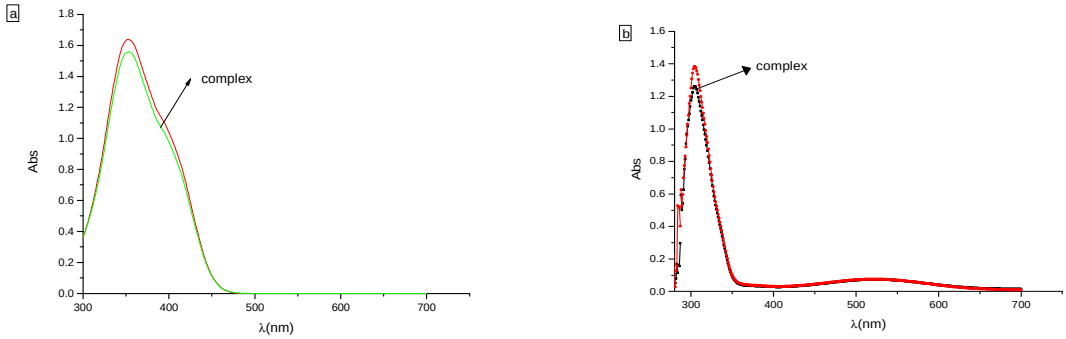


Fig 2: Electronic absorption Spectra of: (a) Ty-PA and (b)Ty-CA.

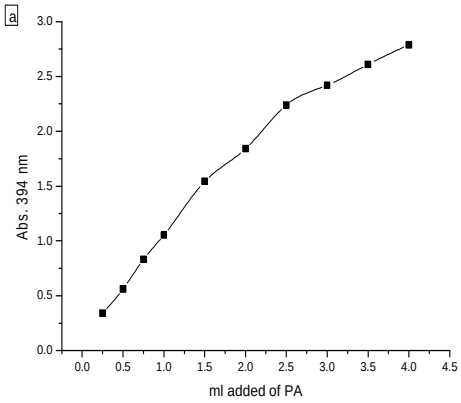


Fig 3: Photometric titration curve for the Ty- PA system at 394 nm.

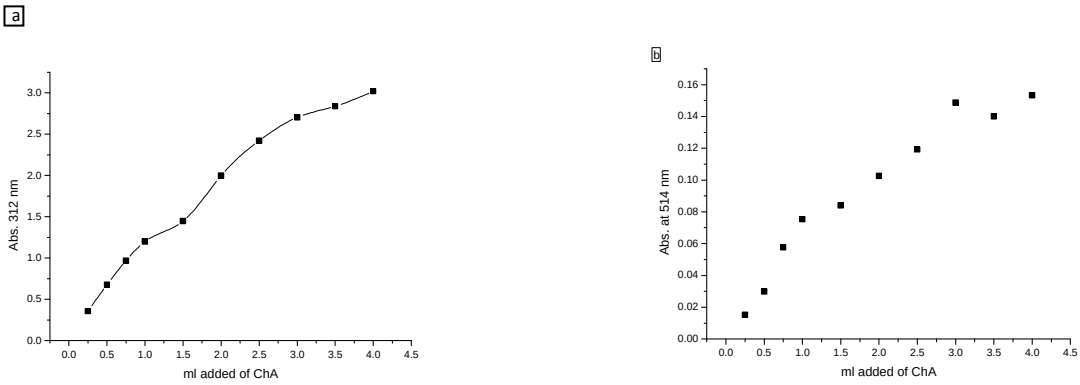


Fig 4: Photometric titration curve for the Ty-ChA system at a) 312 nm and b) 514nm

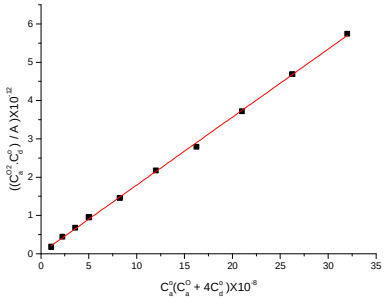


Fig 5: The plot of ($C_A^{o\,2}.C_D^{o}$)/A values vs $C_A^{o}\left(4C_D^{o} + C_A^{o}\right)$ values for the Ty-PA at 394 nm.

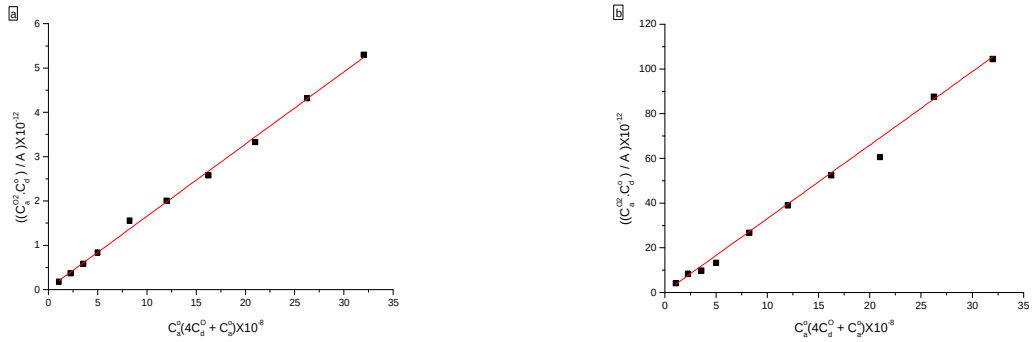


Fig 6: The plot of ($C^{o\,2}_A .C^{o}_D$)/A values vs $C^{o}_A\left(4C^{o}_D + C^{o}_A\right)$ values for the Ty-CA at a) 312 nm and b) 514 nm

Table1: Spectrophotometric data of: (a) Ty-PA and (b) Ty-CA CT complexes

Complex	K/l.mol^{-1}	λ_{max}/nm	ε_{max}/l.mol^{-1}.cm^{-1}	I_p	E_{CT}	R_N	ΔG°	f	μ
Tyramine-picric acid	9.30×10^4	394	5.64×10^4	9.64	3.16	5.8	-28.35	10.59	29.62
Tyramine-chloronilic acid	6.76×10^4	312	6.136×10^4	10.67	3.99	6.68	-27.53	58.83	63.3
	17.53×10^4	514	0.304×10^4	8.73	2.42	3.6	-29.92	0.932	10.10

UV–vis absorption spectra of Ty-CA and Ty-PA CT complexes were scanned in MeOH solvent. The concentration of Ty in the reaction mixture was kept fixed at 1.0×10−4M in MeOH solvent, while, the concentration of PA or CA was changed from 0.25×10−4M to 4.0×10−4 M. These concentrations were covered along the range from 1:0.25 to 1:4.00. The UV–vis spectra of Ty-CA and Ty-PA systems were shown in Fig. 2A and B. The measured spectra were detected definite absorption bands which are not existed in both spectra of the free donor and acceptors. These bands are noticed at (394 nm) and (312 and 514 nm) due to CT-complexes formed from the reactions of Ty with PA and CA, respectively. Photometric titration curves based on charge transfer bands are shown in Fig. 3A and Band Fig 4A and B respectively. These photometric titration curves were obtained according to well known method and it is refereed to formation of 1: 2 CT complexes. The 1: 2 ratio equation (1) was used in the calculations.

$$\frac{CA^{\circ 2}C^{\circ}_D}{A} = \frac{1}{K_\varepsilon} + \frac{1}{\varepsilon}.C^{\circ}_A(4C^{\circ}_D + C^{\circ}_A) \qquad \text{eq1}$$

where $C^{\circ 2}_A$ and C°_2 are the initial concentration of the π-acceptor (PA and CA) and donor (Ty), respectively, and A is the absorbance of the detected CT-band. The data obtained C°_D, $C^{\circ 2}_A$, $C^{\circ}_A(4C^{\circ}_D + C^{\circ}_A)$ and $(C^{\circ 2}_A .C^{\circ}_D)/A$ in methanol were calculated. By plotting $(C^{\circ 2}_A .C^{\circ}_D)/A$ values vs $C^{\circ}_A(4C^{\circ}_D + C^{\circ}_A)$, straight lines were obtained with a slope of 1/ε and an intercept of $1/k_\varepsilon$ as shown in Fig. 5, 6. The oscillator strength f was obtained from the approximate formula.

$$f = (4.319 \times 10^{-9})\varepsilon_{max}.\upsilon_{1/2} \qquad \text{eq 2}$$

Where $\upsilon_{1/2}$ is the band-width for half-intensity in cm^{-1} and ε_{max} is the maximum extinction coefficient of the CT-band. The oscillator strength values are given in Table 1. The data resulted reveals several items. (i) The Ty /PA and Ty /CA systems show high values of both formation constant (K) and molar absorptivity (ε).

This high value of (K) reflects the high stability of the Ty complexes as a result of the expected high donation of the Ty which contains amino and hydroxy groups. (ii) The different values of the oscillator strength, f, increases with increasing in the dielectric constant (D) of the solvent. This result could be explained on the basis of competitive solvent interactions with the acceptors. The transition dipole moment (–) of the Ty CT-complexes, Table 1, has been calculated from Eq. (3)

$$m(\text{Debye}) = 0.0958[\varepsilon_{max}\upsilon_{1/2}/\upsilon_{max}]^{1/2} \qquad \text{eq 3}$$

The transition dipole moment is useful for determining if transitions are allowed, that the transition from a bonding π orbital to an antibonding π* orbital is allowed because the integral defining the transition dipole moment is nonzero.

The ionization potential (Ip) of the Ty donor in the charge transfer complexes of (Ty/PA and Ty/CA) are calculated using empirical equation derived by Aloisi and Piganatro Eq. (4)

$Ip(ev) = 5.76 + 1.53 \times 10^{-4} \nu CT$ eq 4

where ν_{CT} is the wavenumber in cm^{-1} corresponding to the CT band formed from the interaction between donor and acceptor. The electron donating power of a donor molecule is measured by its ionization potential which is the energy required to remove an electron from the highest occupied molecular orbital. The energy of the charge-transfer complexes E_{CT} of the Ty complexes is calculated using Eq. (5)

$E_{CT} = (h\nu_{CT}) = 1243.667/\lambda_{CT}$ (nm) eq5

Where, λ_{CT} is the wavelength of the complexation band.

Determination of resonance energy (R_N) theoretically derived from (Eq. 6)

$$\varepsilon_{max} = \frac{7.7 \times 10^{-4}}{h\nu_{CT} / [R_N - 3.5]}$$ eq 6

Where ε_{max} is the molar absorptivity of the CT-complexes at maximum CT band, ν_{CT} is the frequency of the CT peak and $\boldsymbol{R_N}$ is the resonance energy of the complex in the ground state, which, obviously is a contributing factor to the stability constant of the complex (a ground state property). The values of $\boldsymbol{R_N}$ for the (PA and CA) complexes under study have been given in Table 1.

The standard free energy changes of complexation (ΔG◦) were calculated from the formation constants by the following Eq. (7).

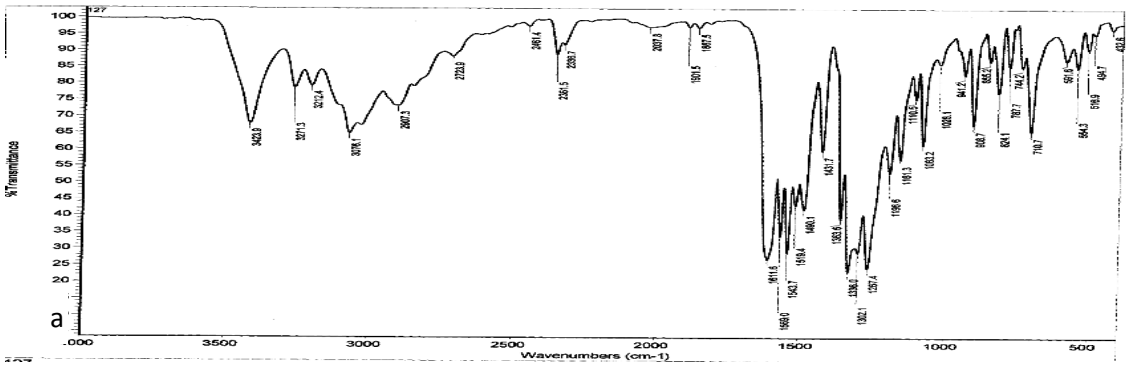
$$\Delta G^{\circ} = -2.303RT \log K_{CT}$$ eq 7

Where $\Delta \boldsymbol{G}^{\circ}$ is the free energy change of the CT-complexes (KJ mol^{-1}), R is the gas constant (8.314 $Jmol^{-1}$ K), T is the temperature in Kelvin degrees (273+ ◦C) and K_{CT} is the formation constant of the complexes (l mol^{-1}) in different solvents at room temperature. [25]

3.2 IR studies

Infrared spectra of the electron donor (Ty) and its CT complexes with both PA and CA acids as acceptors are shown in Figure 7 a and b respectively. Comparison between the spectra of both CT-complexes and the data of Ty donor and acceptors have been studied and recorded in Table 2. In the spectra of the CT complexes, each one provides the main characteristic bands for both donor and acceptor in each case.

This observation strongly supports the formation of the CT interaction between donor and acceptors. A small shifts in both band intensities and wave number values shown when compare CT complexes with free molecules, due to changes of molecular symmetries and electronic structures of the reactants upon complexation.



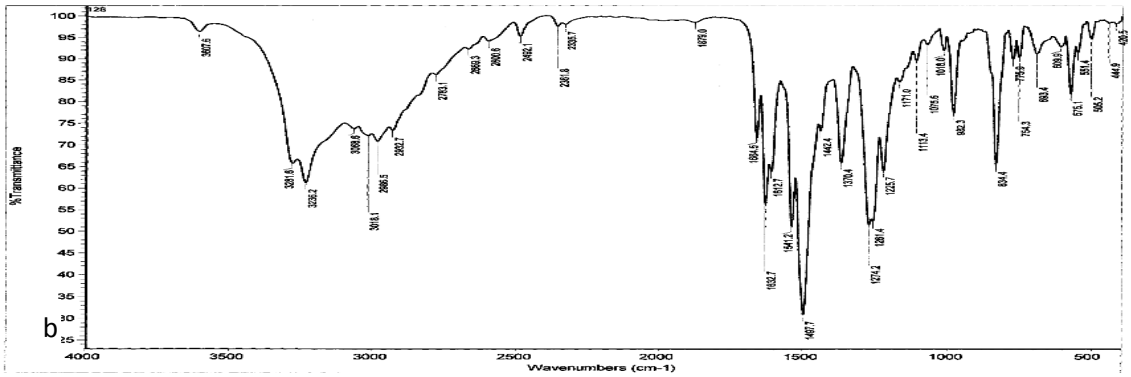


Figure 7: Infrared spectra of Ty CT complexes with a- PA and b- CA.

Table 2: Infrared frequencies (cm^{-1}) for Ty, CA, PA, [(Ty)$(CA)_2$], [(Ty)$(PA)_2$] CT-complexes

Ty*	CA	PA	Ty\CA	Ty\ PA	Assignments
3669	3420 $_{s,br}$	3416 $_{br}$	3607 $_{vw}$		O-H
3263 3344	3235 $_{s,br}$	3103 $_{s}$	3281 3236	3271 3212	N-H
2897 2968	-	-	3018	2850 2907	CH_2 symmetry
2937 3026	-	-	2986 2932	3000 3076	CH_2 asymmetry
1263	-	-	1274	1267	C-O
796 77o	-	-	754 775	744 710	C-N stretching
-	-	-	2783 2670 2601	2723 2650 2550	Hydrogen bonding
-	-	1632	-	1612	NO_2 in PA

** ref [27]*

The Infrared spectra of the molecular complexes of CA and PA with donors indicate that *v*(C–Cl) of CA and *v*(NO_2) of PA are shifted to lower wave number values upon complexation and the stretching frequency of C-O bond of the acceptor displays a shift to a higher wave number values. Infrared spectra of the synthesized complexes show a strong band in the range between 2500-2800 cm^{-1}, indicating +N–H…OH stretching vibration of the intermolecular hydrogen bond and a protonation of the NH group of the donor through one proton transfer from CA through (OH) to the N-H and OH groups in the basic centre(Ty). On the other hand, the intermolecular hydrogen bond occurs in the PA from the OH group to the basic central nitrogen atom and hydroxyl group of the donor (Ty). The vibration motions which indicates that the interactions placed among the –OH group of each of CA and PA and –NH_2 group of Ty through the hydrogen bonding existed at 2783 w, 2670 vw, 2601 vw for Ty /CA and 2723 w, 2650 w, 2550 w for Ty/PA. These new bands were attributed to the stretching vibration of a proton attached to the donation site (–NH_2) of the donor and forming NH_3^+group [31]. As expected, the bands characteristic for the Ty unit in [(Ty)$(CA)_2$] and [(Ty)$(PA)_2$] CT-complexes are existed with small changes in band intensities and frequency values. This could be attributed to the expected symmetry and electronic structure changes upon the formation of the CT-complexes.

3.3- ^{1}H-NMR spectral study

New signals are observed in ^{1}H-NMR for the synthesized complexes assigned to +N–H proton which resulted from the protonation of N atom of donors. The O–H signals of the free CA and PA were disappeared on complex formation. A new signal appears at 7.76 ppm which indicates a hydrogen bond between hydroxyl groups from Ty and PA and at δ = 6.7ppm and 6.4ppm was appear as indication of NH_3^+. These data is agreed quite well with the UV-visible and FT-IR studies. The ^{1}H-NMR spectra for Ty/PA and Ty/CA CT complexes appear in figure 8 and 9 respectively. ^{1}HNMR of Ty and the formed CT complexes were carried out in DMSO. The ^{1}HNMR spectrum of the Ty CT complex a and b was compared with that of the parent Ty. A new signals at δ = 6.7ppm and 6.4ppm was appear as indication of NH_3^+ formed of PA and CA CT complexes respectively and at δ = 7.8ppm and 8.0ppm corresponding to hydrogen bond (OH ---- O) in PA and CA CT complexes respectively is another indication to form complex. Figure 8 show a new signal at δ = 8.8ppm corresponding to hydrogens of PA-CT complex, in figure 9 another signal appear at δ = 9.5 ppm corresponding to enol forms CT complex and its tautomerism keto enol between δ = 5.1- 5.6ppm for both CA ligand due to the different in its direction. The signals within the range of δ = 6.9-7.3 ppm are assigned to the protons of the benzene ring. The CH_2-N proton is shifted to δ = 2.7 and 2.6 ppm for PA and CA CT complexes respectively with dramatic decrease in intensity and lower shifting to 2.9 and 2.8 for PA and CA CT complexes respectively of (CH_2-Ph) group is another indication to form complex.

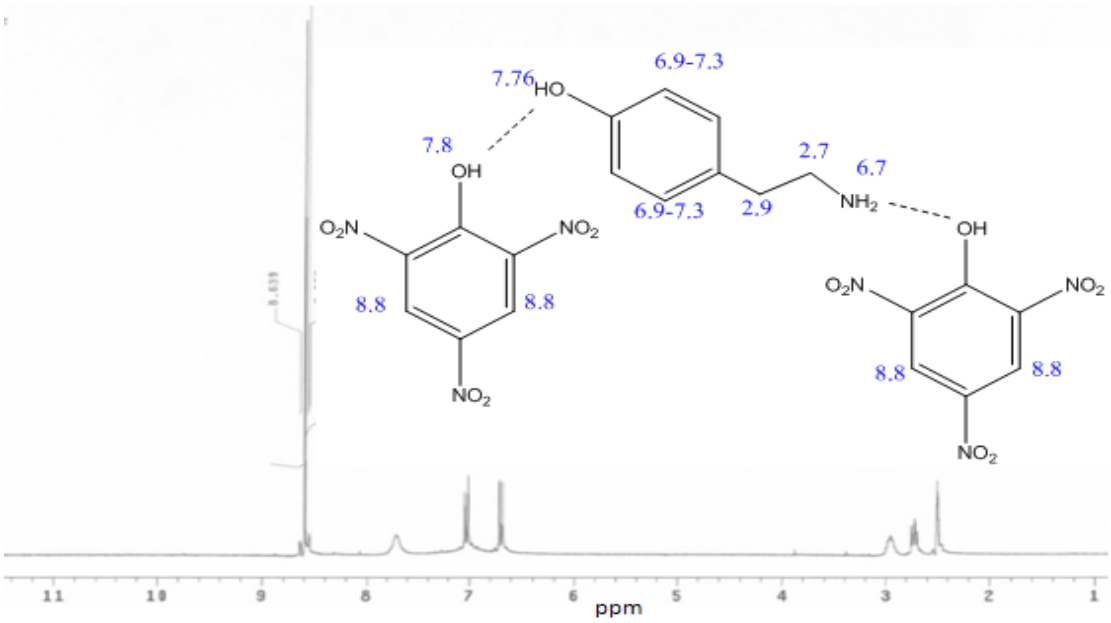


Figure 8: ^{1}H-NMR spectrum of [(Ty)(PA)$_2$] CT complex.

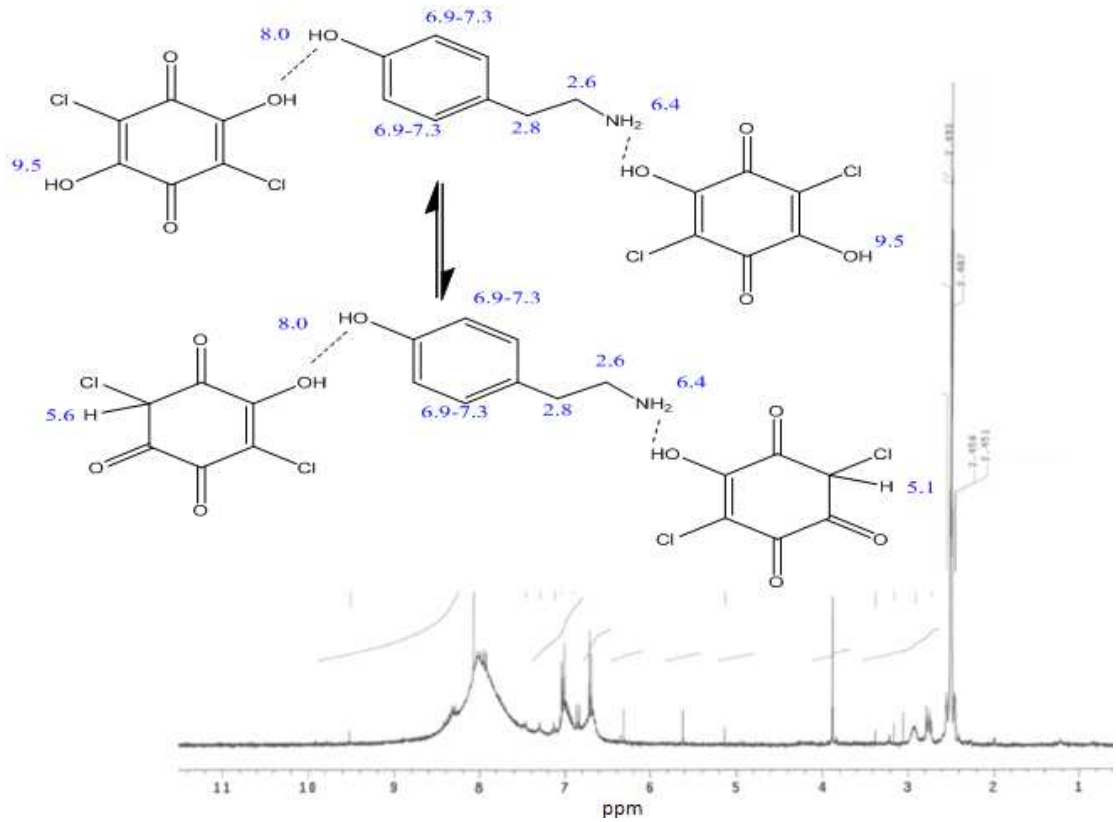


Figure 9: ^{1}H-NMR spectrum of [(Ty)(CA)$_2$] CT complex.

3.4. Thermogravimetric studies

The thermo gravimetric analysis give an idea about the thermal stabilities of the prepared charge transfer complexes and also show the different in physical behavior between the starting and resulting compounds. TG curves of Ty CT complexes are shown in Fig. 10 and 11.

TG curve of [(Ty)(PA)$_2$] CT-complex was thermally decomposed in nearly two decomposition steps within the temperature rang 25–800 ◦C. The first decomposition step (obs= 58.16 %) within the temperature range 25–290 ◦C, may be assigned to the liberation of $C_6H_2Cl_2O_2$+ $2Cl_2$+ $2H_2O$+ NH_3 and C_2H_6 molecules. The second decompo-

setion step found within the temperature range 290 - 685 ◦C (obs = 42.3 %) which are assigned by the removal of 6C+ $2O_2$ and C_6H_6 molecules with remaining a carbon atoms as a final residual.

TG curve of $[(Ty)(CA)_2]$ CT-complex was thermally decomposed in nearly two decomposition steps within the temperature rang 25–800 ◦C. The first decomposition step (obs= 58.96 %) within the temperature range 25–297 ◦C, may be assigned to the liberation of $C_6H_3N_3O_7$ and $C_8H_{11}N$ molecules. The second decomposition step found within the temperature range 297 - 635 ◦C (obs = 39.9 %) which are assigned by the removal of $C_5H_4N_3O_8$ molecules with remaining a carbon atom as a final residual.

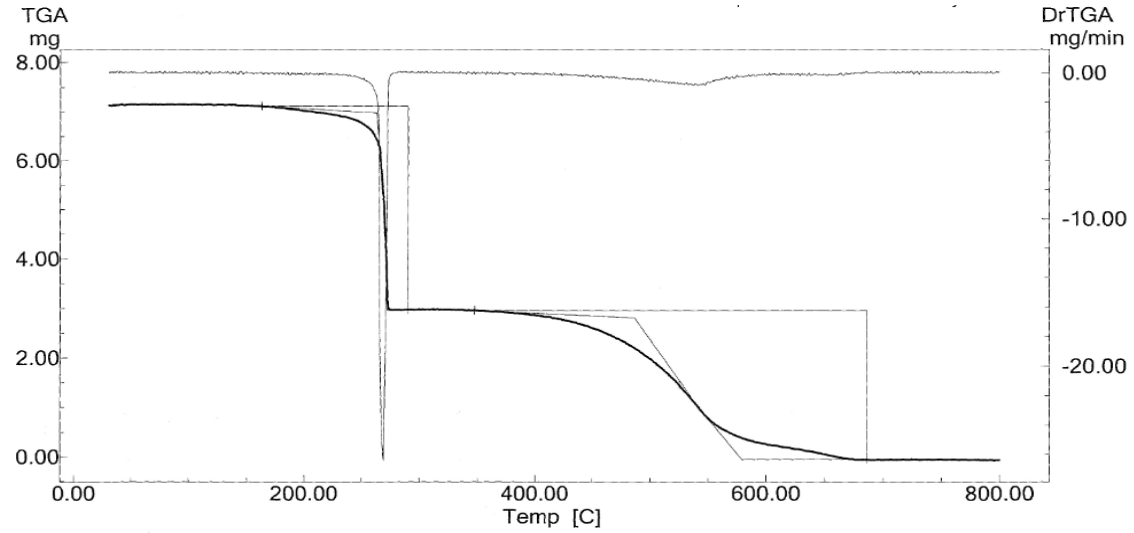


Fig.10. TG curves of Ty- PA CT complex.

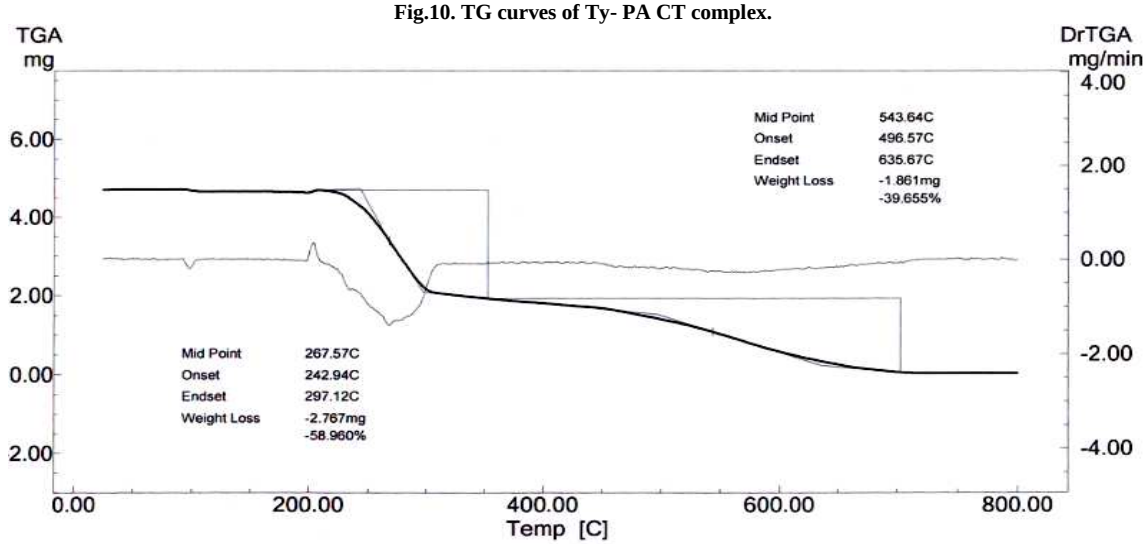


Fig.11. TG curves of Ty- CA CT complex.

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