



King Saud University  
Journal of Saudi Chemical Society

[www.ksu.edu.sa](http://www.ksu.edu.sa)  
[www.sciencedirect.com](http://www.sciencedirect.com)



## ORIGINAL ARTICLE

# Synthesis and spectroscopic characterization on the tri-iodide charge transfer complex resulted from the interaction between morpholine as donor and iodine $\sigma$ -acceptor

Moamen S. Refat <sup>a,b,\*</sup>, Hamdy Al. Didamony <sup>c</sup>, Khlood M. Abou El-Nour <sup>d</sup>,  
Lamia El-Zayat <sup>a</sup>

<sup>a</sup> Department of Chemistry, Faculty of Science, Taif University, 888 Taif, Saudi Arabia

<sup>b</sup> Department of Chemistry, Faculty of Science, Suez Canal University, Port Said 42111, Egypt

<sup>c</sup> Department of Chemistry, Faculty of Science, Zagazig University, Zagazig, Egypt

<sup>d</sup> Department of Chemistry, Faculty of Science, Suez Canal University, Ismailia, Egypt

Received 9 January 2010; accepted 16 February 2010

Available online 14 April 2010

## KEYWORDS

Morpholine;  
Iodine;  
Charge-transfer complex;  
Infrared spectra;  
Tri-iodide ion

**Abstract** Charge-transfer (CT) complex formed between morpholine (Morp) as donor with iodine ( $I_2$ ) as acceptor has been studied spectrophotometrically. The synthesis and characterization of morpholine CT-complex of iodine,  $[(Morp)_2]I^+ \cdot I_3^-$  was described. This complex is readily prepared from the reaction of Morp with  $I_2$  within  $CHCl_3$  solvent. IR spectra, UV–Vis techniques and elemental analyses (C, H and N), characterize the Morp charge-transfer complex. Benesi–Hildebrand and its modification methods were applied to the determination of association constant ( $K$ ), molar extinction coefficient ( $\epsilon$ ).

© 2010 King Saud University. Open access under [CC BY-NC-ND license](http://creativecommons.org/licenses/by-nc-nd/3.0/).

\* Corresponding author at: Department of Chemistry, Faculty of Science, Taif University, 888 Taif, Saudi Arabia.

E-mail addresses: [msrefat@yahoo.com](mailto:msrefat@yahoo.com) (M.S. Refat), [hdidamony80@yahoo.com](mailto:hdidamony80@yahoo.com) (H. Al. Didamony), [khloodabouelnour@yahoo.com](mailto:khloodabouelnour@yahoo.com) (K.M. Abou El-Nour), [lamia\\_zayat@yahoo.com](mailto:lamia_zayat@yahoo.com) (L. El-Zayat).

1319-6103 © 2010 King Saud University.

Open access under [CC BY-NC-ND license](http://creativecommons.org/licenses/by-nc-nd/3.0/).

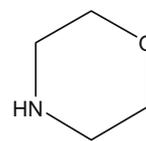
doi:10.1016/j.jscs.2010.04.004



Production and hosting by Elsevier

## 1. Introduction

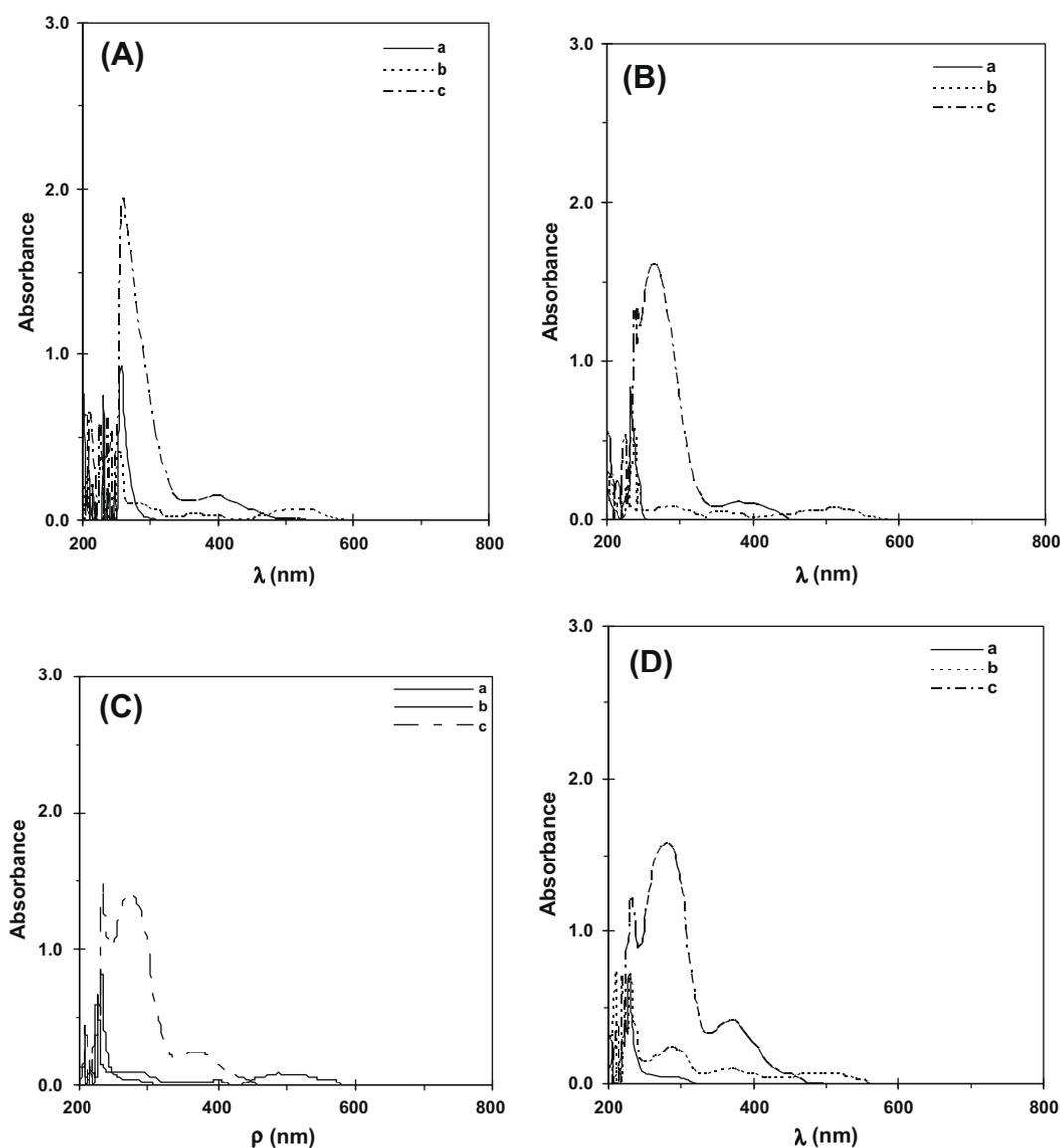
Morpholine (Morp) is an organic chemical compound having the chemical formula  $O(CH_2CH_2)_2NH$  (Formula I). Morpholine is a common additive, in ppm concentrations, for pH adjustment in both fossil fuel and nuclear power plant steam systems. Morpholine is widely used in organic synthesis. For example, it is a building block in the preparation of the antibiotic linezolid and the anticancer agent.



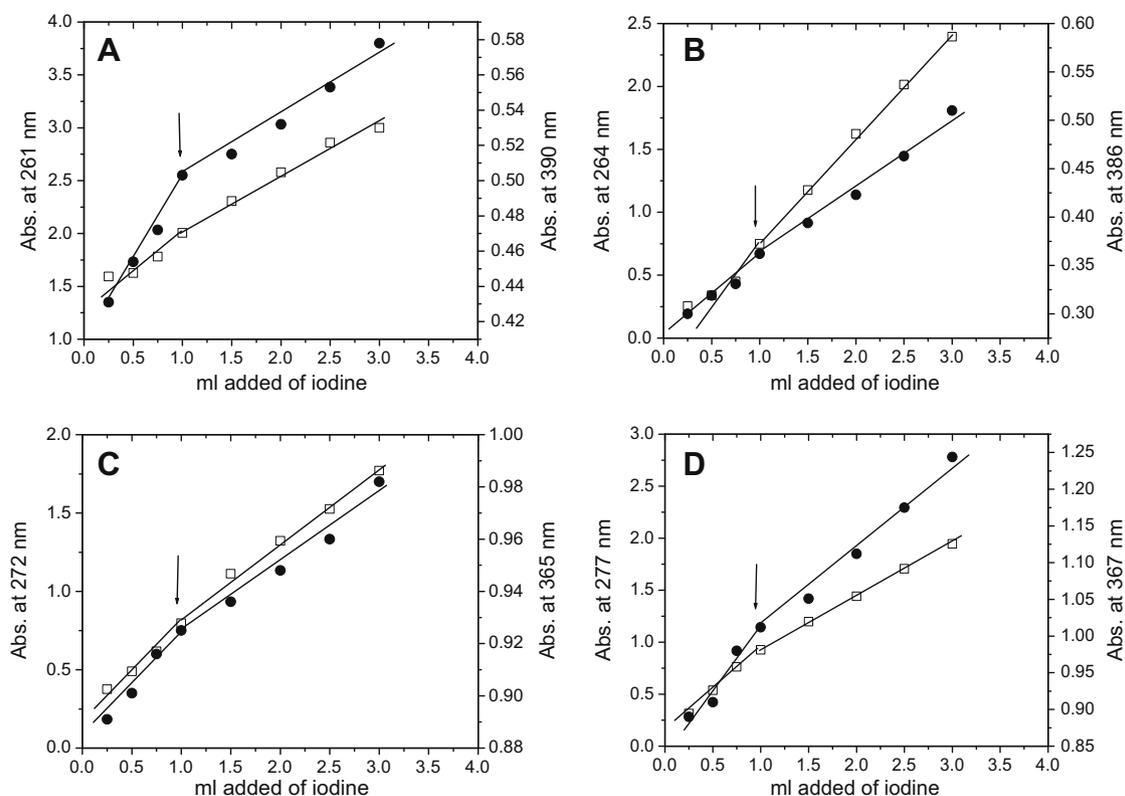
Structure of Morpholine (I)

**Table 1** Elemental analysis CHN and physical parameters data of the CT-complex formed in the reaction of the Morp with iodine.

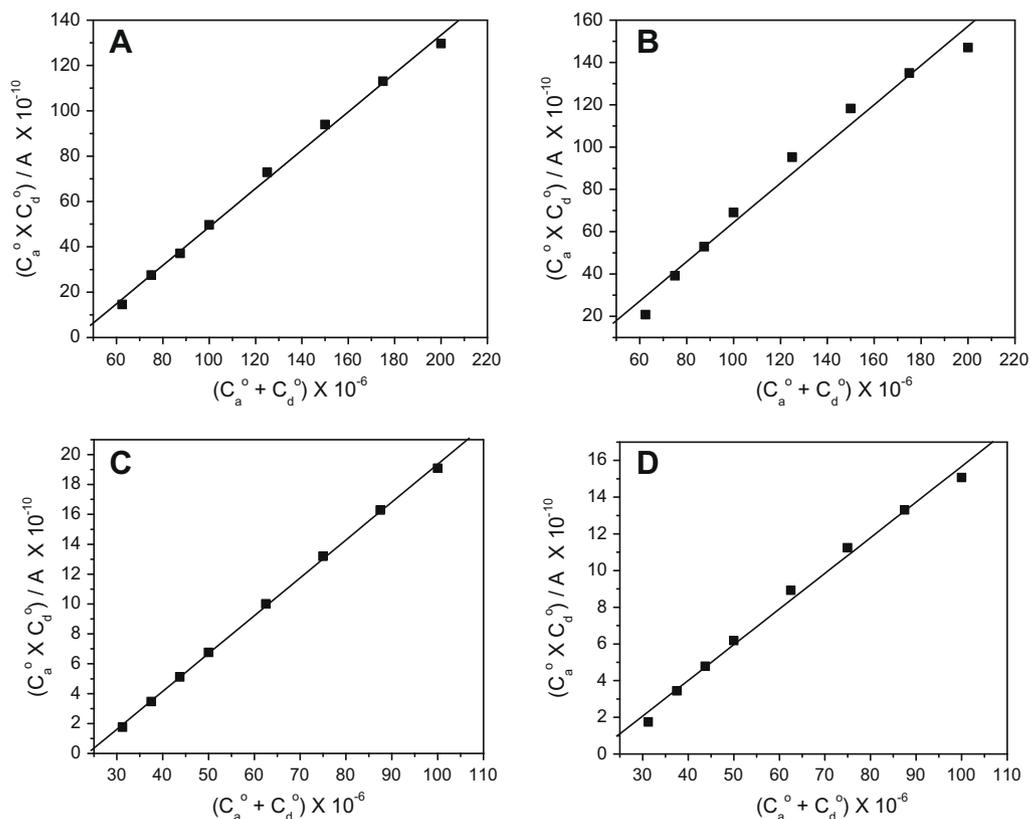
Complexes (FW)	Molecular weight	C%		H%		N%		Physical data	
		Found	Calc.	Found	Calc.	Found	Calc.	Color	mp (°C)
$[(Morp)_2]I^+ \cdot I_3^-$ ( $C_8H_{18}N_2O_2I_4$ )	682.00	13.98	14.10	2.56	2.64	3.98	4.11	Yellow	63



**Figure 1** Electronic absorption spectra of: (A) Morp-iodine reaction in  $CCl_4$ , (B) Morp-iodine reaction in  $CHCl_3$ , (C) Morp-iodine reaction in  $CH_2Cl_2$  and (D) Morp-iodine reaction in 1,2-dichloroethane. (a) = donor ( $1.0 \times 10^{-4}$  M), (b) = acceptor ( $1.0 \times 10^{-4}$  M) and (c) = CT-complex.



**Figure 2** Photometric titration curves for the Morp-iodine system in various solvents; (A) in CCl<sub>4</sub> at 261 and 390 nm, (B) in CHCl<sub>3</sub> at 264 and 386 nm, (C) in CH<sub>2</sub>Cl<sub>2</sub> at 272 nm and 365 nm and (D) in 1,2-dichloroethane at 277 nm and 367 nm.



**Figure 3** The plot of  $(C_a^o + C_d^o)$  values against  $C_a^o \cdot C_d^o / A$  values for the Morp-iodine system in various solvents; (A) in CCl<sub>4</sub> at 390 nm, (B) in CHCl<sub>3</sub> at 386 nm, (C) in CH<sub>2</sub>Cl<sub>2</sub> at 365 nm and (D) in 1,2-dichloroethane at 367 nm.

**Table 2** Spectrophotometric results of the Morp complex with iodine in different solvents at 25 °C and the dielectric constant of the solvents.

Solvent	$\lambda_{\max}$ (nm)	$E_{CT}$ (eV)	$K$ (l mol <sup>-1</sup> )	$\epsilon_{\max}$ (l mol <sup>-1</sup> cm <sup>-1</sup> )	$f$	$\mu$	$I_p$	$D$
CCl <sub>4</sub>	390	3.18	$2.36 \times 10^4$	$1.18 \times 10^4$	5.79	21.90	7.75	2.2
CHCl <sub>3</sub>	386	3.22	$3.26 \times 10^4$	$1.08 \times 10^4$	7.29	24.50	7.80	4.7
CH <sub>2</sub> Cl <sub>2</sub>	365	3.40	$4.23 \times 10^4$	$3.94 \times 10^4$	23.60	42.80	8.08	8.9
(CH <sub>2</sub> ) <sub>2</sub> Cl <sub>2</sub>	367	3.38	$5.17 \times 10^4$	$5.14 \times 10^4$	30.80	49.00	8.05	10.4

Some of charge-transfer complexes show very interesting applications in the field of analytical chemistry (Bebawy and El-Kelani, 1997; Luo, 1995). Polyiodide charge-transfer complexes are of special interest and importance. This is because some of these complexes have shown interesting properties such as electrical conductivity. The highly conducting complex  $[(TTT)_2]I^+ \cdot I_3^-$  is reported (Trotter and White, 1978) to be formed in the reaction of iodine with the sulphur containing base tetrathiotetracene (TTT).

In previous studies (Mizuno et al., 1981; Nour et al., 1986a,b; Mulazzi et al., 1981; Nour, 2000; Nour and Shahada, 1988), it has been stated that iodine reacts with bases like cyclic polyamines, polysulphur and mixed oxygen–nitrogen to form stable charge-transfer complexes with the formation of polyiodide ions  $I_n^-$  ( $n = 3, 5, 7$  and 9).

In continuity with our interest in the study of interaction of charge-transfer (CT) complexes Teleb, 2004; Refat et al., 2004, 2005, 2006a,b, 2007; Refat, 2005, the present article includes the characterization of charge-transfer complex of Morp with iodine as acceptor. Association constants ( $K$ ), molar extinction coefficient ( $\epsilon$ ), oscillator strength ( $f$ ) are evaluated. The solid complex was synthesized and studied by elemental analysis (CHN), infrared and electronic spectra.

## 2. Materials and methods

All chemicals used throughout this work were Analar or extra pure grade. Morphiline,  $O(CH_2CH_2)_2NH$ , was of analytical reagent grade (Merck reagent). Iodine as a  $\sigma$ -acceptor was purchased from Aldrich. Stock solutions of morphiline or iodine acceptor were freshly prepared and the spectroscopic grade chloroform (Merck Co.) was used as received.

### 3. [Morphiline]–iodine complex

The morphiline–iodine CT-complex with the general formula  $[(Morp)_2]I^+ \cdot I_3^-$ , was isolated as a dark brown solid by the mixing (87.12 mg, 1.0 mmol) of the donor in chloroform (10 ml), a solution of iodine was added (253.81 mg, 1.0 mmol) in the same solvent (10 ml) with continuously stirring for about 15 min at room temperature and the solution was allowed to evaporate slowly at room temperature. A yellow crystal was formed, washed several times with little amounts of chloroform, and dried under vacuum over anhydrous calcium chloride; the empirical formula of the complex  $[(Morp)_2]I^+ \cdot I_3^-$  is  $C_8H_{18}N_2O_2I_4$  with molecular weight 682.00 g/mol.

### 4. Instrumentation and physical measurements

The Electronic spectra of the donors, iodine and the resulted CT-complex 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 was performed at 25 °C for the reactions of Morp donor with iodine acceptor in chloroform, as follows: the concentration of the donor in the reaction mixtures was kept fixed at  $5.0 \times 10^{-4}$  M, while the concentration of iodine was 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.

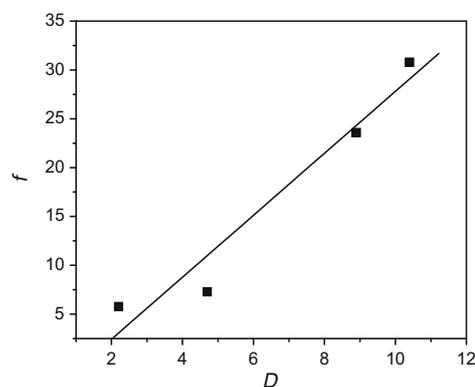
IR measurements (KBr discs) of the solid donors, acceptor and CT-complexes were carried out on a Bruker FT-IR spectrophotometer (400–4000 cm<sup>-1</sup>).

## 5. Results and discussion

The elemental analysis data (C, H and N) of the Morp charge transfer complex were performances and listed in Table 1. From this table, it can be seen that the resulted values are agree quite well with the calculated values, and the suggested of the CT-complex is matched with the molar ratios introduced from the photometric titration curves. The entire Morp CT-complex is insoluble in cold and hot water, but easily soluble in DMF and DMSO.

### 6. Electronic absorption spectra of Morp/iodine system

The UV–Vis absorption spectra of the iodine complex were measured in various solvents such as CCl<sub>4</sub>, CHCl<sub>3</sub>, CH<sub>2</sub>Cl<sub>2</sub> and 1,2-dichloroethane. In each solvent the complex is formed by adding  $X$  ml of  $5.0 \times 10^{-4}$  M (iodine) ( $X = 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, 2.50$  and  $3.00$  ml) to 1.00 ml of  $5.0 \times 10^{-4}$  M morpholine. The volume of the mixture in each case was completed to 10 ml for (CCl<sub>4</sub>), 10 ml for (CHCl<sub>3</sub>), 20 ml for (CH<sub>2</sub>Cl<sub>2</sub>) and 20 ml for (1,2-dichloroethane) with the respected



**Figure 4** The plot of the oscillator strength  $f$  of  $[(Morp)_2]I^+ \cdot I_3^-$  against the dielectric constant of the solvent  $D$ .

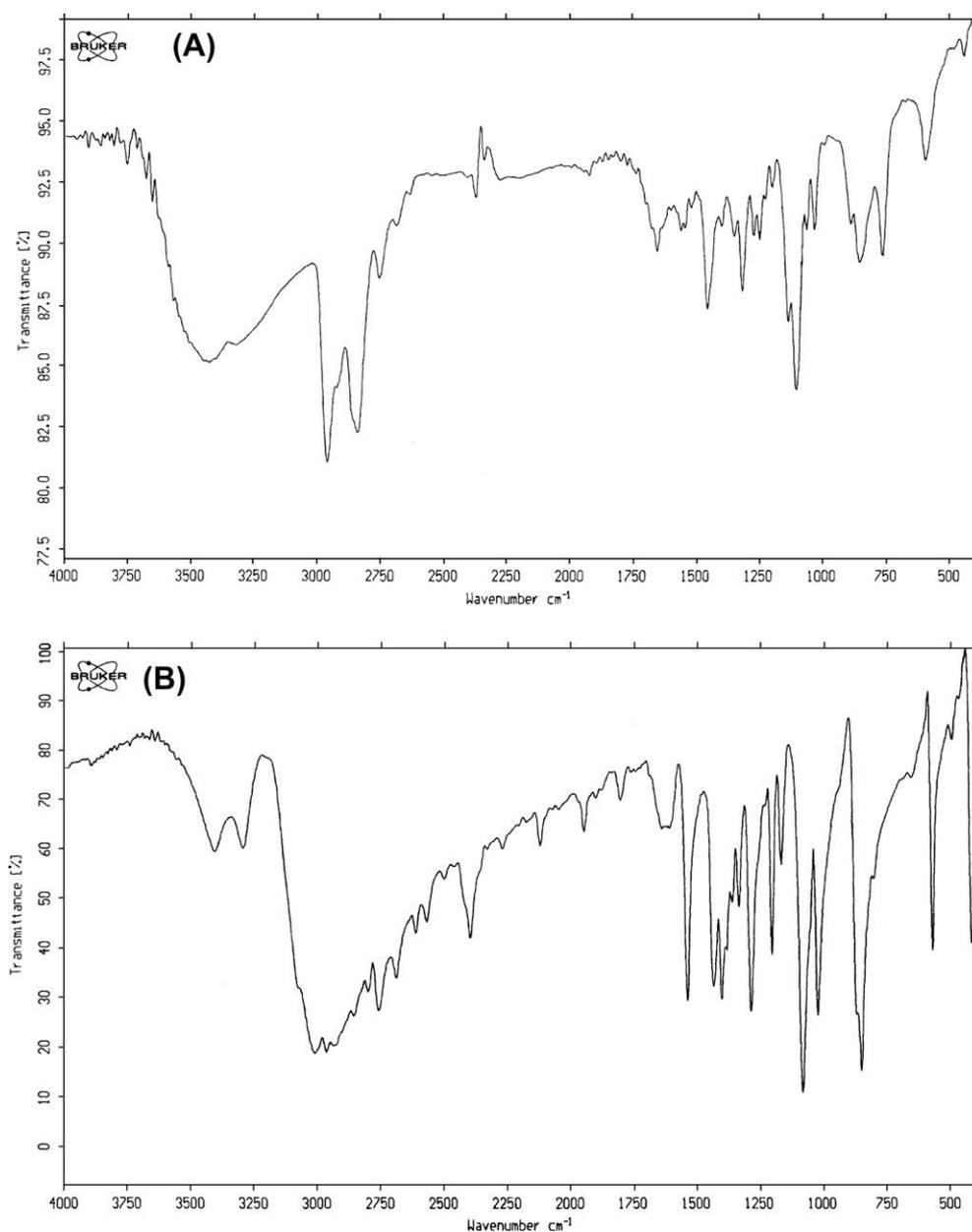
solvent. The concentration of Morp in the reaction mixture was kept fixed at  $0.50 \times 10^{-4}$ ,  $0.50 \times 10^{-4}$ ,  $0.25 \times 10^{-4}$  and  $0.25 \times 10^{-4}$  M in the case of using  $\text{CCl}_4$ ,  $\text{CHCl}_3$ ,  $\text{CH}_2\text{Cl}_2$  and 1,2-dichloroethane solvents, respectively. While the concentration of iodine was varied over the range of  $0.125 \times 10^{-4}$  M to  $1.50 \times 10^{-4}$  M for Morp/ $\text{I}_2$  system in  $\text{CCl}_4$  solvent, from  $0.125 \times 10^{-4}$  M to  $1.500 \times 10^{-4}$  M for Morp/ $\text{I}_2$  system in  $\text{CHCl}_3$  solvent, from  $0.0625 \times 10^{-4}$  M to  $0.7500 \times 10^{-4}$  for Morp/ $\text{I}_2$  system in  $\text{CH}_2\text{Cl}_2$  and from  $0.0625 \times 10^{-4}$  M to  $0.7500 \times 10^{-4}$  M for Morp/ $\text{I}_2$  system in 1,2-dichloroethane solvent, respectively. These concentrations produce Morp:  $\text{I}_2$  ratios extending along the range from 1:0.25 to 1:3.00. The electronic absorption spectra of the 1:1 ratio in  $\text{CCl}_4$ ,  $\text{CHCl}_3$ ,  $\text{CH}_2\text{Cl}_2$  and 1,2-dichloroethane together with the reactants  $\text{I}_2$  and Morp are shown in Fig. 1A–D, respectively.

The spectra show characteristic real absorption bands which are not present in the spectra of the reactants free iodine

and Morp. These bands are assigned at (390 and 261 nm), (386 and 264 nm), (365 and 272 nm) and at (367 and 277 nm) due to the CT-complex formed in the reaction mixtures of Morp with  $\text{I}_2$  in the solvents  $\text{CCl}_4$ ,  $\text{CHCl}_3$ ,  $\text{CH}_2\text{Cl}_2$  and 1,2-dichloroethane, respectively. Photometric titration curves based on these characterized absorption bands are given in Fig. 2A–D.

These photometric titration curves were obtained according to the known methods (Skoog, 1985) by the plot of the absorbance against the X ml added of the iodine  $\sigma$ -acceptor. The equivalence points shown in these curves clearly indicate that the formed CT-complex between Morp and iodine is 1:1. The formation of 1:1 complex was strongly supported by elemental analysis, mid and far infrared spectra.

However, the appearance of the two absorption bands around  $\approx 360$  and  $\approx 270$  nm are well known (Kiefer and Bernstein, 1972; Andrews et al., 1980; Kaya et al., 1972), to be characteristic for the formation of the tri-iodide ion ( $\text{I}_3^-$ ).



**Figure 5** Infrared spectra of: (A) Morp and (B) The charge-transfer complex,  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$ .

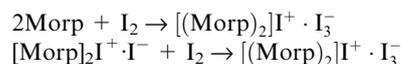
Accordingly, the formed complex was formulated as  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$ .

It was of interest to observe that the solvent has an effect on the spectral intensities of the formed  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$  complex. To study the solvent effect in a quantitative manner, it was necessary to calculate the values of the equilibrium constant,  $K$ , the extinction coefficient  $\epsilon$  and the oscillator strength,  $f$ , of the iodine complex in each solvent. The 1:1 modified Benesi–Hildebrand equation (Abu-Eittah and Al-Sugeir, 1976) was used in the calculations.

Where  $C_a^0$  and  $C_d^0$  are the initial concentrations of the acceptor ( $\text{I}_2$ ) and the donor Morp, respectively, and  $A$  is the absorbance of the detected bands around 270 and 360 nm. When the  $C_a^0 \cdot C_d^0/A$  values for each solvent are plotted against the corresponding  $(C_a^0 + C_d^0)$  values. Straight lines are obtained with a slope of  $1/\epsilon$  and intercept of  $1/k\epsilon$  as shown in Fig. 3A–D for the reaction mixtures in  $\text{CCl}_4$ ,  $\text{CHCl}_3$ ,  $\text{CH}_2\text{Cl}_2$  and 1,2-dichloroethane. The oscillator strength  $f$  was obtained from the approximate equation (Tsubomura and Lang, 1964). Where  $\nu_{1/2}$  is the band-width for half-intensity in  $\text{cm}^{-1}$ . The oscillator strength values together with the corresponding dielectric constants,  $D$ , of the solvent used are given in Table 2. The trend of the values in this table reveals several facts. (i) The  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$  shows high values of both the equilibrium constant ( $K$ ) and extinction coefficient ( $\epsilon$ ). This high value of ( $K$ ) reflects the high stability of the iodine complex as a result of the expected high donation of the Morp, while the high value of ( $\epsilon$ ) agrees quite well with the existence of tri-iodide ion,  $\text{I}_3^-$ , which is known to have high absorptivity value (Kiefer and Bernstein, 1972; Andrews et al., 1980; Kaya et al., 1972). (ii) The 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 acceptor (Ayad, 1994). Fig. 4 shows the obtained linear relationship between  $f$  and  $D$ . (iii) The formation constant ( $K$ ) for the  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$  shows some variation, Table

2, as the solvent is changed, but no clear relation with solvent properties can be obtained.

Finally, the general mechanism for the formation of  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$  complex is proposed as follows:



The formation of  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$  reaction intermediate is analogous to the well known species  $[(\text{donor})\text{I}]^+ \cdot \text{I}^-$  formed in the reaction of iodine with many donors (Hassan, 2004; Rabie, 2006). It has characteristic (Harada et al., 1981) absorption, around 250 nm; see Fig. 3A–D. The transition dipole moment ( $\mu$ ) of the iodine complex, Table 2, have been calculated from the equation (Rathone et al., 1997). The ionization potential ( $I_p$ ) of the free donor was determined from the CT energies of the CT band of its complexes with iodine by using the following equation (Aloisi and Pignataro, 1973; Foster, 1969; Kinoshita, 1962):

$$I_p (\text{eV}) = 2.90 + 1.89 \times 10^{-4} \nu (\text{cm}^{-1})$$

where  $E_{\text{CT}}$  is the energy of the charge-transfer of the iodine complex, the energy of the  $\pi-\sigma^*/n-\sigma^*$  interaction ( $E_{\text{CT}}$ ) is calculated using the following equation (Briegleb, 1960a,b).

## 7. Infrared spectra of the Morp–iodine solid complex

The mid infrared spectra of Morp and the solid CT-complex,  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$ , were recorded from KBr discs. These spectra are shown in Fig. 5A and B, respectively. The spectral bands are resolved and assigned into their vibrational modes and given in Table 3. As expected, the bands characteristic for the Morp unit in  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$  CT-complex are shown with small changes in both band intensities and frequency values. For example, the  $\nu(\text{N-H})$  vibration occur at 3424 and (splitting, 3418 and 3306)  $\text{cm}^{-1}$  for free Morp and

**Table 3** Infrared frequencies<sup>a</sup> ( $\text{cm}^{-1}$ ) and tentative assignments for Morp donor and  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$  complex.

Morp	$[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$	Assignments <sup>b</sup>
3424 s, br, 3300 w, sh	3418 ms, 3306 ms	$\nu(\text{N-H})$
2959 vs	3023 w	$\nu_s(\text{C-H})$
2839 vs	2977 vw	$\nu_{\text{as}}(\text{C-H})$
2753 mw, 2686 vw	2867 vw, 2812 w, 2771 ms, 2702 ms	
—	2624 w, 2580 w, 2511 vw, 2408 s	Hydrogen bonding
1655 ms	1645 ms	$\delta_{\text{def}}(\text{N-H})$
		Ring breathing bands
1561 vw	1552 vs	C–H deformation
1545 vw, 1521 vw, 1457 s, 1400 w	1449 s, 1416 s	
1351 w	1348 ms	$\nu(\text{C-C})$
1318 s	1301 vs	$\nu(\text{C-N})$
1273 w	1218 vs	$\nu(\text{C-O-C})$
1250 w, 1228 w, 1200 w, 1136 sh, 1106 vs, 1064 w, 1033 ms	1181 s, 1098 vs, 1038 s	
890 vw	867 vs	(C–H) bend
856 s		$\delta_{\text{rock}}; \text{NH}$
765 s	667 vw	$\text{CH}_2$ Rock
		Skeletal vibrations
595 s	584 vs	CNC deformation
442 mw	507 vw, 430 w	

<sup>a</sup> s = strong, w = weak, m = medium, sh = shoulder, v = very, br = broad.

<sup>b</sup>  $\nu$ , stretching;  $\delta$ , bending.

$[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$ , respectively. The decreasing in the intensity of  $\delta(\text{N-H})$  vibration in case of iodine complex rather than Morp alone as well as the blue shifted in the wavenumbers from  $1655 \text{ cm}^{-1}$  (Pip) to  $1645 \text{ cm}^{-1}$  (iodine complex). Such these changes clearly indicate that the N-H bond in Morp donor is involved in the complexation process with iodine. On the other side, the presence of collected bands at 2771, 2702, 2624, 2580, 2511 and  $2408 \text{ cm}^{-1}$  value, these could be assigned to the expected hydrogen bonding in the Morp/iodine complex

(Bellamy, 1975). This fact is strongly interpretation the mode of interaction between Morp and iodine by forming hydrogen bond between donor "Morp" and "iodine" acceptor (N-H...I).

### 9. Far infrared spectra of the Morp-iodine solid complex

The far infrared spectrum of  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$  was recorded from Nujol mulls dispersed on polyethylene windows in the

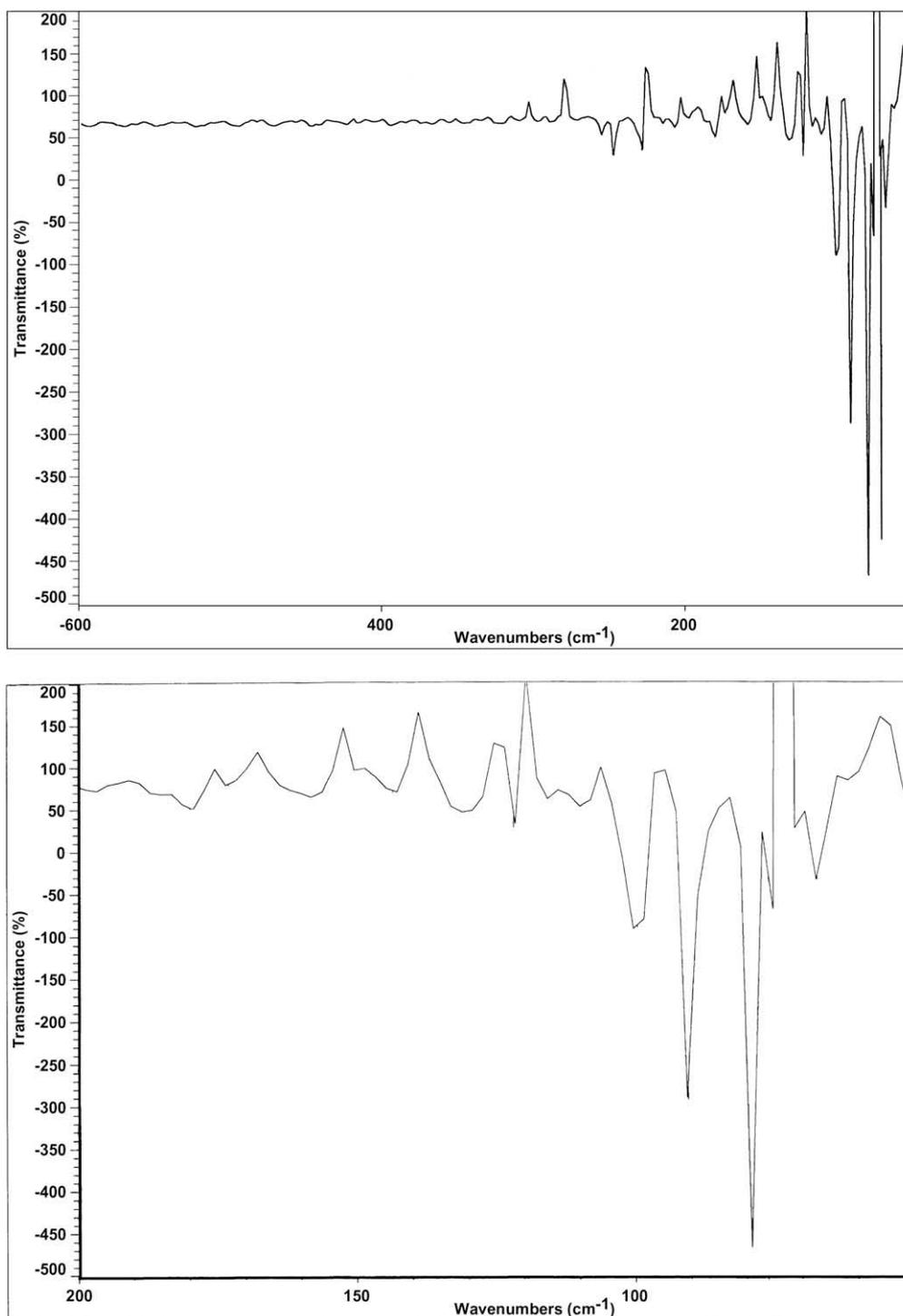


Figure 6 Far-infrared spectrum of the charge-transfer complex,  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$ .

region 50–200  $\text{cm}^{-1}$  and shown in Fig. 6. The spectrum associated with the  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$  complex shows the detected bands distinguished for the tri-iodide ion,  $\text{I}_3^-$  at 158, 109 and 79  $\text{cm}^{-1}$ . These bands can be attributed to the  $\nu_{\text{as}}(\text{I}-\text{I})$ ,  $\nu_{\text{s}}(\text{I}-\text{I})$  and  $\delta(\text{I}_3^-)$ , respectively. These three absorption bands do not exist in the spectrum of the donor, Morp. However, the  $\text{I}_3^-$  ion may be linear ( $D_{\infty h}$ ) or non-linear ( $C_{2v}$ ). Group theoretical analysis indicates that the  $\text{I}_3^-$  with  $C_{2v}$  symmetry displays three vibrations  $\nu_{\text{s}}(\text{I}-\text{I})$ ;  $A_1$ ,  $\nu_{\text{as}}(\text{I}-\text{I})$ ;  $B_2$  and  $\delta(\text{I}_3^-)$ ;  $A_1$ , all are infrared active in agreement (Kiefer and Bernstein, 1972; Maki and Forneris, 1967; Parrett and Taylor, 1970) with the observed three infrared bands for  $[(\text{Morp})_2]\text{I}^+ \cdot \text{I}_3^-$ .

## References

- 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.
- Andrews, L., Prochaska, E.S., Loewenschuss, A., 1980. *Inorg. Chem.* 19, 463.
- Ayad, M.M., 1994. *Spectrochim. Acta Part A* 50 (4), 671.
- Bebawy, L.I., El-Kelani, L., Fattah, Abdel, Ahmed, A.S., 1997. *J. Pharm. Sci.* 86 (9), 1030.
- Bellamy, L.J., 1975. *The Infrared Spectra of Complex Molecules*. Chapman & Hall, London.
- Briegleb, G., 1960a. *Z. Angew. Chem.* 72, 401.
- Briegleb, G., 1960b. *Z. Angew. Chem.* 76, 326.
- Foster, R., 1969. *Organic Charge Transfer Complexes*. Academic Press, London.
- Harada, I., Tanaka, J., Zuno, M.M., 1981. *J. Phys. Chem.* 85, 1789.
- Hassan, Kh.A., 2004. *Spectrochim. Acta Part A* 60 (13), 3059.
- Kaya, K., Mikami, N., Udagawa, Y., Ito, M., 1972. *Chem. Phys. Lett.* 16, 151.
- Kiefer, W., Bernstein, H.J., 1972. *Chem. Phys. Lett.* 16, 5.
- Kinoshita, M., 1962. *Bull. Chem. Soc. Jpn.* 1609, 12.
- Luo, M., 1995. *Yaowu Fenxi Zazhi* 15 (6), 52.
- Maki, A.G., Forneris, R., 1967. *Spectrochim. Acta Part A* 23, 867.
- Mizuno, M., Tanaka, J., Harada, I., 1981. *J. Phys. Chem.* 85, 1789.
- Mulazzi, E., Pollini, I., Piseri, L., Tubino, R., 1981. *Phys. Rev. B* 24, 3555.
- Nour, E.M., 2000. *Spectrochim. Acta Part A* 56, 167.
- Nour, E.M., Shahada, L.A., 1988. *Spectrochim. Acta Part A* 44, 1277.
- Nour, E.M., Chen, L.H., Laane, J., Raman, J., 1986a. *J. Raman Spectrosc.* 17, 467.
- Nour, E.M., Chen, L.H., Laane, J., 1986b. *J. Phys. Chem.* 90, 2841.
- Parrett, F.W., Taylor, N.J., 1970. *J. Inorg. Nucl. Chem.* 32, 2458.
- Rabie, U.M., 2006. *Collect. Czech. Chem. Commun.* 71 (9), 1359.
- Rathone, R., Lindeman, S.V., Kochi, J.K., 1997. *J. Am. Chem. Soc.* 119, 9393.
- Refat, M.S., 2005. *J. Korean Chem. Soc.* 49 (1), 35.
- Refat, M.S., Aqeel, S.M., Grabchev, I., 2004. *Can. J. Anal. Sci. Spectrosc.* 49 (4), 258.
- Refat, M.S., Teleb, S.M., Grabchev, I., 2005. *Spectrochim. Acta Part A* 61 (1–2), 205.
- Refat, M.S., Sadeek, S.A., Khater, H.M., 2006a. *Spectrochim. Acta Part A* 64 (3), 778.
- Refat, M.S., Grabchev, I., Chovelon, J.-M., Ivanova, G., 2006b. *Spectrochim. Acta Part A* 64 (2), 435.
- Refat, M.S., El-Didamony, A.M., Grabchev, I., 2007. *Spectrochim. Acta Part A* 67 (1), 58.
- Skoog, D.A., 1985. *Principle of Instrumental Analysis*, third ed. Saunders College Publishing, New York, USA (Chapter 7).
- Teleb, S.M., Refat, M.S., 2004. *Spectrochim. Acta Part A* 60 (7), 1579.
- Trotter, P.J., White, P.A., 1978. *Appl. Spectrosc.* 32, 232.
- Tsubomura, H., Lang, R.P., 1964. *J. Am. Chem. Soc.* 86, 3930.