CHAPTER 7

FTIR SPECTROSCOPY OF CHARGE TRANSFER COMPLEXES OF HORMONES
7.1 Introduction

Spontaneous electrical activities in mammary epithelial cells are due to insulin [1]. FTIR spectroscopy of amyloid formation by insulin is studied [2]. The conformational stability and flexibility of insulin with cross-links have been studied [3]. Chemical properties of the functional groups of insulin have been a subject of a study [4]. Fibrillation of monomeric insulin has been studied [5]. FTIR with circular dichroism and electron microscopy of insulin amyloid fibrils are studied [6]. Biodegradable insulin nano-capsules are also prepared [7]. Colorimetry and FTIR spectroscopy of bovine insulin are carried out [8]. Theory of hopping conduction in pig insulin has been developed [9]. An even dielectric property of insulin has been studied [10]. Conformational influence of hopping conductivity in pig insulin is studied [11]. FTIR spectroscopy and electron microscopy of insulin fibrils are studied [12]. Chiral superstructures of insulin amyloid fibril are also studied [13]. Radiation resistivity of frozen solutions and suspensions of insulin has been also a subject of study [14]. Thyrotropin releasing hormone (TRH) is studied with IR spectroscopy method [15]. Role of serum thyrotropin in diagnosis of hyperthyroidism is studied [16]. TRH from pancreas and other extraneural tissues of rats has been studied [17]. Effect of cold-restraint...
stress on immunoreactive TRH in rat stomach has been studied [18]. Synthesis, receptor binding and pharmacological studies of new TRH analogues has been carried out [19]. Decrease in membrane potential by TRH in mouse has been observed [20]. There is an increase in conductance of granular membrane by throtropin [21]. Lipopolysaccharide modulation of TRH is observed in rat brain [22]. TRH induces rise in calcium and outward K\(^+\) current in pituitary cells [23].\(^{13}\)C NMR study of (\(^{13}\)C- enriched proline) thyrotropin releasing factor has been carried out [24]. Isolation and properties of Porcin TRH have been reported [25]. Changes in electrical properties of vasopressin neurons during lactation are reported [26]. Immuno-reactivity regulation of arginine vasopressin is reported [27]. Laser Ramman spectroscopy and circular dichroism studies of lysine vasopressin and arginine vasopressin have been carried out [28]. Biological and chemical properties of lysine vasopressin dimer have been studied [29]. Signalling properties of vasopressin receptor have been verified [30]. Effect of glucagon on the liver cell membrane potential has been studied [31]. NMR study of molecular conformation of momeric glucagon is carried out [32]. Characterization and physical stability of glucagon have been studied [33]. Glucagon has ribbon structure and raises blood glucose levels. Amyloid fibrils of glucagon are characterized by
atomic force microscopy [34]. Laser Ramman spectra of crystalline and aqueous glucagon have been studied [35]. Conformational properties of cyanogens-bromide-eleaved glucagon have been studied [36]. Tight coupling between electrical activity and exocytosis in glucagon secreting cells has been observed [37]. Thermodynamics of the self-association of glucagon is also a subject of study [38]. A conformational study of glucagon has been reported [39]. Glucagon fibril has polymorphism with differences in backbone structure.

In the present work, charge transfer complexes of insulin, TRH, vasopressin and glucagon with organic acceptors have been studied with FTIR spectroscopy.

7.2 Experimental detail

Insulin, thyrotropin-releasing hormone (TRH), vasopressin and glucagon were obtained from standard chemical company such as Sigma-Aldrich chemical company, USA and were highly pure reagent grade. Insulin was mixed with organic acceptors such as TCNQ(7,7,8,8-tetracyano-p-quinodimethane), TCNE (tetracyano-p-ethylene), DDQ(2,3-dichloro-5,6-dicyano-p-benzoquinone), chloranil (2,3,5,6-tetrachloro-p-benzoquinone) and iodine and grinded in agate mortar with a pastle for a
long time. The mixtures were in equal volume proportions and therefore heavily-doped with acceptors. TRH was also mixed with TCNQ, DDQ and KI-I$_2$. Fine homogeneous powders of charge transfer complexes were prepared. Vasopressin and glucagon were mixed with TCNQ only and powders of CTCs were obtained. The CTCs of hormones were further mixed with 95% KBr spectrograde powder and grinded to form semitransparent powders. The powders were compressed in a die with manually operated compressing machine to prepare circular pellets. These circular discs were placed in a dark chamber of standard spectrophotometer.

### 7.3 Results and discussion

Three dimensional molecular structure of insulin, vasopressin and glucagon and chemical structure of glucagon are shown in figure 7.1a-c. The FTIR spectrum of insulin is shown in figure 7.2a. The spectrum shows a half-power beta density in the range 2870-1800 cm$^{-1}$ associated hopping conduction of polarons as charge carriers shown in figure 7.2b. It also contains a low frequency gaussian band centered around 624 cm$^{-1}$ as shown in figure 7.2c. Between these two regions, there is a region of nature of interband transition. It is a forbidden direct or allowed indirect transition in two dimensions with $E_g \approx 0.185$ eV. The band gap is even
smaller than Peierls gap which should be about 0.225eV. This band gap shows that insulin is a small band gap semiconductor. Insulin molecules are regularly stacked and parallel stack form energy band structure in such a manner that there is only a small band gap. Insulin has a fibrous structure and grows in the form of fibrils. Molecular packing in nanomaterial is such that it is a layered compound and shows intrinsic conduction in two dimensions. The small band gap is due to layered nature having extra degree of freedom. Charge carriers do not face a Peierls gap of one dimensional case.
Figure 7.2a The FTIR spectrum of insulin

Figure 7.2b Half-power beta density of insulin

Figure 7.2c Gaussian band fitted in insulin
The FTIR spectrum of insulin-TCNQ is shown in figure 7.3a. It contains a low-frequency Gaussian band around 623 cm$^{-1}$ which is fitted as shown in figure 7.3b. There is a Hubbard gap which is non-universal of 0.285 eV which is neither Peierls gap of TCNQ stacks nor the band gap due to insulin stacks. Charge transfer interaction is responsible for this forbidden direct gap as shown in figure 7.3c. The band gap along insulin stacks is reduced to 0.12 eV form 0.185 eV due to interaction with TCNQ. Stacking of insulin molecules is such that there is allowed indirect transition in one-dimensional as shown in figure 7.3d. Thus insulin molecules no longer form a two-dimensional network due to insertion of TCNQ molecules.
Figure 7.3 a The FTIR spectrum of insulin-TCNQ CTC

Figure 7.3 b Gaussian band fitted in insulin-TCNQ CTC

Figure 7.3 c Hubbard gap showing forbidden direct transition in insulin-TCNQ CTC
The FTIR spectrum of insulin-TCNE is shown in figure 7.4a. The half-power beta density associated with the hopping of polaron is again seen and fitted accordingly as shown in figure 7.4b. A Hubbard gap of 0.31eV is observed because of charge transfer interaction between insulin and TCNE as shown in figure 7.4c. This transition is of allowed indirect type. The band gap along insulin stacks reduces to 0.115eV even lesser than TCNQ complex and this transition is of forbidden indirect type which is fitted as in figure 7.4d.
Figure 7.4 b Half-power beta density in insulin-TCNE CTC

Figure 7.4 c Hubbard gap showing in insulin-TCNE CTC

Figure 7.4 d Band gap along insulin stacks showing forbidden indirect transition in insulin-TCNE CTC
The FTIR spectrum of insulin-DDQ is shown in figure 7.5a. Here a Hubbard gap of 0.24eV has opened (figure 7.5b) and the band gap of insulin stacks is found to be of the order of 0.155eV as shown in figure 7.5c. Both of the transitions are of forbidden indirect type. Finally, a gaussian band around $606\text{cm}^{-1}$ is very weak and broad which is shown in figure 7.5 d.

The FTIR spectrum of insulin-chloranil is also shown in figure 7.6a. A band gap of 0.255eV is observed with allowed indirect transition as shown in figure 7.6 b. Rest of the spectrum below $1600\text{cm}^{-1}$ shows oscillations in density of states along chloranil stacks as found in many chloranil complexes. These are square-root singularities along homomolecular chloranil stacks similar to monatomic lattice.
Figure 7.5 b Hubbard gap showing forbidden indirect transition in insulin-DDQ CTC

Figure 7.5 c Band gap insulin stacks showing forbidden indirect transition in insulin-DDQ CTC

Figure 7.5 d Gaussian band fitted in insulin-DDQ CTC
The FTIR spectrum of insulin-iodine is also displayed as shown in figure 7.7a. The higher band gap of 0.31eV is with forbidden indirect transition as shown in figure 7.7b, while the lower gap is 0.20eV with similar transition as shown in figure 7.7c. The band gap along insulin stacks has increased from 0.185eV to 0.20eV. Finally a gaussian band around 564cm\(^{-1}\) is also fitted as shown in figure 7.7d.
Figure 7.7 a The FTIR spectrum of insulin-iodine CTC

Figure 7.7 b Hubbard gap showing forbidden indirect transition in insulin-iodine CTC

Figure 7.7 c Band gap along insulin stacks showing forbidden indirect transition in insulin-iodine CTC
The FTIR spectrum of thyrotropin-releasing hormone (TRH) is shown in figure 7.8a. A half-power beat density between 2885 cm\(^{-1}\) and 1700 cm\(^{-1}\) is observed which is associated with hopping of small polarons and is fitted as shown in figure 7.8b. The band gap along TRH stacks is found to be about 0.13 eV with allowed direct transition as shown in figure 7.8 c. Finally an intense gaussian band around 640 cm\(^{-1}\) is observed which is fitter as shown in figure 7.8d. Thus TRH is also a small band gap semiconductor and band gap is lesser than a Peierls gap.
Figure 7.8a Half-power beta density in thyrotropin-releasing hormones (TRH)

Figure 7.8c Band gap along TRH stacks showing allowed direct transition in thyrotropin-releasing hormone (TRH)

Figure 7.8d Gaussian band fitted in thyrotropin-releasing hormone (TRH)
The FTIR spectrum of TRH-TCNQ is also shown in figure 7.9a. It shows two regions of nature of transitions- one with $E_g=0.28\text{eV}$ and the other with $E_g=0.12\text{eV}$. Thus a Hubbard gap of 0.28eV opens in a charge transfer ionic complex and the band gap along TRH stack reduces from 0.13eV to 0.12eV as shown in figure 7.9b and 7.9c respectively. A gaussian band observed around 596cm$^{-1}$ is fitted as shown in figure 7.9 d.

The FTIR spectrum of TRH-DDQ is shown in figure 7.10a. It shows a Hubbard gap of 0.235eV and also a band gap of 0.185eV along TRH stacks as shown in figure 7.10b and 7.10c respectively. A gaussian band around 625cm$^{-1}$ is also fitted as shown in figure 7.10d.

![Figure 7.9 a The FTIR spectrum of TRH-TCNQ charge transfer complex](image)
Figure 7.9 b Hubbard gap showing forbidden indirect transition in TRH-TCNQ CTC

Figure 7.9 c Band gap along TRH stacks showing allowed direct transition in TRH-TCNQ CTC

Figure 7.9 d Gaussian band fitted in TRH-TCNQ charge transfer complex
Figure 7.10 a The FTIR spectrum of TRH-DDQ CTC

Figure 7.10 b Hubbard gap showing forbidden indirect transition in TRH-DDQ CTC

Figure 7.10 c Band gap along TRH stacks showing allowed direct transition in TRH-DDQ CTC
The FTIR spectrum of TRH-KI-I$_2$ is shown in figure 7.11a. It also shows two band transport with Hubbard gap of about 0.22eV and band gap along TRH stacks of about 0.118eV as shown in figure 7.11b and 7.11c respectively. The lower gap is with forbidden direct or allowed indirect type transition in a layered material. Thus TRH-KI-I$_2$ is a two-dimensional conductor. A broad gaussian around 620cm$^{-1}$ is also fitted as shown in figure 7.11d.
Figure 7.11 b Hubbard gap showing forbidden indirect transition in TRH-KI-I$_2$ CTC

Figure 7.11 c Band gap along TRH stacks showing allowed direct transition in TRH-KI-I$_2$ CTC

Figure 7.11 d Gaussian band fitted in TRH-KI-I$_2$ CTC
The FTIR spectrum of vasopressin is shown in figure 7.12a. A half-power beta density associated with polaron hopping is observed which if fitted as shown in figure 7.12b. There is an allowed direct transition with small band gap of 0.125eV along the stacks of vasopressin molecules as shown in figure 7.12c. A gaussian band 625cm\(^{-1}\) is fitted as shown in figure 7.12d.

![Figure 7.12 a The FTIR spectrum of vasopressin only](image)

![Figure 7.12 b Half-power beta density in vasopressin only](image)
The FTIR spectrum of vasopressin-TCNQ is shown in figure 7.13a. A half-power beta density $3200\text{cm}^{-1}$ and $1700\text{cm}^{-1}$ is observed related with polaron hopping and is fitted as shown in figure 7.13b. The band gap of vasopressin stacks is increased to $0.18\text{eV}$ but leaving transition to be of allowed direct type as shown in figure 7.13c. Finally a weak and broad gaussian band at low frequency is fitted as shown in figure 7.13d.
Figure 7.13 a The FTIR spectrum of vasopressin-TCNQ CTC

Figure 7.13 b Half-power beta density in vasopressin-TCNQ CTC

Figure 7.13 c Band gap along vasopressin stacks showing allowed direct transition in vasopressin-TCNQ CTC
The FTIR spectrum of glucagon is shown in figure 7.14a. A half-power beta density revealing polaron hopping is fitted as shown in figure 7.14b. A weak and broad gaussian band at low frequency is also fitted as shown in figure 7.14c. Glucagon remains transmitting throughout the infrared range except weak gaussian band at low frequency. This shows insulating nature of glucagon and the reason is rigid bends or kinks in the structure of glucagon similar to rigid bends in linoleic acid and arachidonic acid.

Finally, the FTIR spectrum of glucagon-TCNQ is shown in figure 7.15a. It contains a half-power beta density which is retained in TCNQ complex and it is due to polaron hopping along an amorphous glucagon as shown in figure 7.15b. Finally, a low frequency gaussian band which is always found is fitted as shown figure 7.15c.
Figure 7.14 a The FTIR spectrum of glucagon only

Figure 7.14 b Half-power beta density in glucagon only

Figure 7.14 c Gaussian band fitted in glucagon
Figure 7.15 a The FTIR spectrum of glucagon-TCNQ CTC

Figure 7.15 b Half-power beta density in glucagon-TCNQ CTC

Figure 7.15 c Gaussian band fitted in glucagon-TCNQ CTC
7.4 Conclusion

Insulin, TRH and vasopressin are small band gap semiconductors only glucagon is an insulator due to rigid bends. The CTCs of hormones are found to show two band transports with one valence band and two conduction bands. One of them (the higher one) is non-universal Hubbard gap and the lower gap is along stacks of hormone molecules. Vasopressin-TCNQ and glucagon-TCNQ seem to be Peierls semiconductors with band gap along TCNQ dimers.

Reference


3. David N. Brems, et. Al., The conformational stability and flexibility of insulin with an additional intramolecular cross-link, The journal of


16. Monika F. Bayer, et. Al., Diagnostic performance of sensitive measurement of Serum Thyrotropin during severe nonthyroidal illness:


18. Thyrotropin-releasing hormone, From Wikipeida, the free encyclopedia


24. Wolfgang Haar, et. Al., \( ^{13}\)C-nuclear magnetic resonance study of \([^{85}\%^{13}\)C-enriched proline ] thyrotropin releasing factor: \(^{13}\)C-\(^{13}\)C vicinal coupling constants and conformation of the proline residue, Proc. Nat. Acad. Sci. USA, Vol. 72, No. 12, pp. 4948-4952, (1975)


