Crystal structure analysis has gained its importance during the last few decades due to its intense application in the field of material science and medicine particularly in the drug industry. Structure and function are intimately related. The three dimensional structure of the materials will help in formulating structure property/function correlation which in turn will enable to modify materials to suit any requirement. Accurate knowledge of molecular structures is a prerequisite for rational drug design and structure-based functional studies. Thus X-ray crystallographic studies play a vital role on drug design. It provides unambiguous, accurate, and reliable 3-dimensional structural parameters. The knowledge of stereochemistry of the molecules is also derived from single crystal X-ray diffraction studies. The double-helical structure of DNA, the planarity of peptide bond, the triple helical structure of collagen, the globular conformation of enzymes and antibodies-all owe their discoveries to X-ray diffraction studies.

Single-crystal X-ray Diffraction is a non-destructive analytical technique which provides detailed information about the internal lattice of crystalline substances, including unit cell dimensions, bond-lengths, bond-angles, and details of site-ordering. Many molecular substances, including proteins, polymers, and others solidify into crystals under the proper conditions. When solidifying into the crystalline state, the individual molecules typically adapt one of only a few possible orientations. A crystal is a three dimensional array of the molecules/atoms/ions that are held together by non-covalent or Van der Waals interactions. The smallest representative unit of crystal is referred to as the unit cell. Understanding the unit cell of these arrays simplifies the understanding of a crystal as a whole. In single-crystal X-ray Diffraction, the data generated from the X-ray analysis is interpreted and refined to obtain the crystal structure. This is the basis of crystallography.

Piperazines are found in biologically active compounds across a number of different therapeutic areas such as antifungal, antibacterial, antimalarial, antipsychotic, antidepressant and antitumour activity against colon, prostate, breast, lung and leukemia tumors. The incorporation of a piperazine moiety generally improves physicochemical properties and thereby enhances biological activities. The
piperazine moiety is extensively employed to construct various bioactive molecules with antipsychotic, antioxidant, antimalarial activity and as cytotoxic agents.

Cinnarizine is a piperazine derivative. Piperazines are a broad class of chemical compounds, many with important pharmacological properties. Cinnarizine is an antihistamine which is mainly used for the control of nausea and vomiting due to motion sickness. Cinnarizine could be also viewed as a nootropic drug because of its vasorelaxating abilities, which happen mostly in brain and is also used as a labyrinthine sedative. In view of the importance of cinnarizine, the crystal and molecular structure studies of cinnarizinium fumarate and cinnarizinium bis(p-toluenesulfonate) dihydrate are reported.

Flunarizine, a piperazine derivative is a nonselective calcium antagonist. It is effective in the prophylaxis of migraine, occlusive peripheral vascular disease, vertigo of central and peripheral origin, and as an adjuvant in the therapy of epilepsy. In view of the importance of flunarizine, the crystal and molecular structure studies of 4-[bis(4-fluorophenyl)methyl]-1-[(2E)-3-phenylprop-2-en-1-yl]piperazin-1-ium-3-carboxy-propanoate, flunarizinium hydrogen maleate, flunarizinium isonicotinate, flunariziniumnicotinate and flunarizinediium bis(4-toluenesulfonate)dihydrate are reported.

Schiff bases are very interesting organic compounds because of their model character and applications from both practical and theoretical points of view. Various applications and the properties of Schiff bases are directly related to the presence of the intermolecular hydrogen bond and the conjugative interactions in the molecules. Some schiff bases play an important role in biological systems. In view of the importance of Schiff bases, the crystal structure of several Schiff bases derived from 1-amino-4-methylpiperazine, viz., 4-methyl-N-(4-nitrobenzylidene)-piperazin-1-amine, N-(1H-indol-3ylmethylidene)-4-methylpiperazin-1-amine and (4-methylpiperazin-1-yl)(2,3,4-trimethoxybenzylidene)amine are reported.

1-(3,4-Methylenedioxybenzyl)piperazine or 1-piperonylpiperazine is a psychoactive drug of the piperazine class and is used to synthesise the drug, piribedil, an antiparkinsonian agent. Piperonylpiperazine derivatives also have α-adrenergic antagonist properties and peripheral vasodilator properties. In view of the importance of 1-piperonylpiperazine, the crystal structure of bis{4-[(1,3-benzodioxol-5-
yl)methyl)piperazin-1-yl)methane, 1-piperonylpiperaziniumpicrate, 1-piperonylpiperazinium-4-chlorobenzoate and 1-piperonylpiperazinium 4-nitrobenzoate monohydrate are reported.

1-((4-Chlorophenyl)(phenyl)methyl)piperazine is a chiral intermediate used for the synthesis of several drugs. Thus piperazine derivatives bearing diphenyl substitution at N1 position also have been introduced to design new antibacterial and antifungal agents, though this moiety has wide application in antihistamine like cetirizine, calcium antagonist (flunarizine) etc. These derivatives were found to possess excellent pharmacological activities such as vasodilator, hypotensive, antiviral activity and cerebral blood flow increasing actions, broad pharmacological action on central nervous system. In view of the importance of piperazine derivative, the crystal and molecular structure of tetraakis-[1-((4-chlorophenyl)(phenyl)methyl)piperazinium]bis(monohydrogensuccinate) succinate monohydrate, bis[1-((4-chlorophenyl) (phenyl)-methyl) piperazinium] chloranilate trihydrate, 1-[4-(4-hydroxyphenyl)piperazin-1-yl]ethanone and 4-(furan-2-carbonyl)piperazin-1-ium 3,5-dinitrobenzoate are reported.

Picric acid forms crystalline picrates with various organic molecules and such picrates are convenient for identification and quantitative analysis of the organic compounds. It is observed that picric acid forms crystalline picrates through well-defined hydrogen bonds and π-bonding. Many organic picrates are of most interest to study because of the presence of hydrogen bonding interactions present. The crystal structure of salts of picric acid with piperazine, viz., 4-acetyl piperazinium picrate, olanzapinum dipicrate and 1-3-chlorophenyl piperazinium picrate are reported.

In this context, the present work aims at the synthesis and crystal structure studies of some pipazine derivatives which have wide importance. In the present work, the crystal and molecular structure studies of twenty one compounds have been reported. The work embodied in this thesis entitled “CRYSTAL AND MOLECULAR STRUCTURE STUDIES OF SOME PIPERAZINE DERIVATIVES” comprises of seven chapters.

Chapter I gives an introduction to single crystal X-ray diffraction, hydrogen bonding and piperazine derivatives. Detailed aspects of single crystal X-ray diffraction are given in this chapter. Chapter I is divided into three sections. Section
1.1 gives the introduction to single crystal X-ray diffraction. **Section 1.2** gives the introduction to hydrogen bonding. **Section 1.3** gives the introduction to piperazine derivatives. In the present work, interest is focused on (a) the preparation of some derivatives (b) crystal data and other relevant parameters regarding data collection, data reduction, structure solution and refinement, (c) atomic co-ordinates of the non-hydrogen atoms with their equivalent displacement parameters, (d) anisotropic displacement parameters, (e) bond lengths and bond angles involving non-hydrogen atoms (f) atomic co-ordinates of the hydrogen atoms, (g) torsion angles, (h) hydrogen bonded interactions, (i) ORTEP of the molecules and (j) packing of the molecules along the crystallographic axes. The structures of all the molecules were solved by direct methods and a discussion based on the above points from (a) to (j) is made individually for all the twenty one compounds.

**Chapter II** describes the preparation and crystal structure studies of some salts of cinnarizine. **Chapter II** is divided into three sections. **Section 2.1**, gives the introduction to cinnarizine. In **section 2.2**, crystal and molecular structure studies of cinnarizinimum fumarate (I), is reported. In the title salt (I), C_{25}H_{29}N_{2}^{+}.C_{4}H_{8}O_{4}^{-}, the piperazine ring in the cation adopts a distorted chair conformation and contains a positively charged N atom with quaternary character. The dihedral angle between the mean planes of the phenyl rings of the diphenylmethyl group is 74.2 (7)° and those between these rings and the phenyl ring of the 3-phenylprop-2-en-1-yl group are 12.7 (9) and 80.6 (8)°. In the crystal, N—H···O and O—H···O hydrogen bonds form chains along [001]. Weak C—H···O interactions connect parallel chains along [010], forming layers perpendicular to a-axis direction. The title compound (I), crystallizes in a monoclinic space group P2_{1}/c with cell constants a = 21.9467(4) Å, b =10.43729(18) Å, c = 11.20623(19) Å, β = 90.0458 (15)°, V = 2566.95(8) Å³, and Z = 4; Dcal = 1.339 Mg/m³ at 173(2) K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final R1 = 0.0405, wR2 = 0.113 using 2134 reflections.

In **Section 2.3**, crystal and molecular structure studies of cinnarizininium bis(p-toluenesulfonate) dihydrate (II), is reported. The asymmetric unit of the title salt, (II), C_{26}H_{30}N_{2}^{2+}.2C_{7}H_{7}O_{3}S^{-}.2H_{2}O, consists of a diprotonated cinnarizininium cation hydrogen bonded through two water molecules to two independent p-toluenesulfonate anions, one which is disordered over two sets of sites in a 0.793
(3):0.207 (3) ratio. In the cation, the piperazine ring adopts a chair configuration and
contains two positively charged N atoms with quaternary character. The dihedral
angle between the two benzene rings in the benzhydryl group is 71.8 (1). The
benzene ring flanked opposite the piperazine ring is twisted by 75.9 (9) and 8.8 (3)°
from these two benzene rings. In the crystal, the hydrogen-bonded asymmetric unit is
connected by further O—H···O hydrogen bonds linking the components into chains
along [100]. The title compound (II), crystallizes in a monoclinic space group $P2_1/n$
and cell constants $a = 10.0845(2)$ Å, $b = 114.6026(3)$ Å, $c = 25.8591(6)$ Å, $\beta =
93.414(2)^\circ$, $V = 3801.25(14)$ Å$^3$, and $Z = 4$; $D_{cal} = 1.309$ Mg/m$^3$ at 100 K. The
structure was solved by direct methods and refined by full-matrix least-squares
procedures to final $R_1 = 0.033$ and $wR_2 = 0.140$; using 7666 reflections.

Chapter III describes the preparation and crystal structure studies of salts of
flunarizine. Chapter III is divided into six sections. Section 3.1 gives the
introduction to flunarizine. In section 3.2, crystal and molecular structure studies of
flunarizinium hydrogen maleate (III), is reported. In the cation of the title salt,
$C_{26}H_{27}F_2N_2^+ \cdot C_4H_3O_4^-$, the protonated piperazine ring is in a chair conformation. The
dihedral angle between the 4-fluorophenyl rings is 68.2(2). An intramolecular O—
H···O hydrogen bond occurs in the anion. In the crystal, N—H···O, C—H···O and C—
H···F interactions are observed, which link the ions into [001] chains. The title
compound (III), crystallizes in a monoclinic space group $P2_1/c$ and cell constants $a =
22.1215(5)$ Å, $b = 10.8620(2)$ Å, $c = 11.3215(2)$ Å, $\beta = 98.879(2)^\circ$, $V = 2687.77(9)$ Å$^3$,
and $Z = 4$; $D_{cal} = 1.286$ Mg/m$^3$ at 173 K. The structure was solved by direct methods
and refined by full-matrix least-squares procedures to final $R_1 = 0.040$ and $wR_2 =
0.136$; using 5264 reflections.

In Section 3.3, crystal and molecular structure studies of flunarizinium
isonicotinate (IV), is reported. In the cation of the title salt $C_{26}H_{27}F_2N_2^+ \cdot C_6H_4NO_2^-$,
the piperazine ring is in a slightly distorted chair conformation. The dihedral angle
between the mean planes of the fluoro-substituted benzene rings is 81.9 (1)º and
these benzene rings form dihedral angles of 6.5 (1) and 87.8 (1)º with the phenyl
ring. In the crystal, a single N—H···O hydrogen bond links the cation and the anion.
In addition, weak C—H···O hydrogen bonds and π–π stacking interactions involving
one of the fluoro-substituted benzene rings and the phenyl ring, with a centroid–
centroid distance of 3.700 (7) Å, link molecules along [100]. The title compound
(IV), crystallizes in a monoclinic space group $Pc$ and cell constants $a = 11.0023(3)$ $\text{Å}$, $b = 10.6435(3)$ $\text{Å}$, $c = 11.3393(3)$ $\text{Å}$, $\beta = 94.481(3)^\circ$, $V = 1326.63(6)$ $\text{Å}^3$, and $Z = 2$; $D_{\text{cal}} = 1.321 \text{Mg/m}^3$ at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final $R_1 = 0.042$ and $wR_2 = 0.110$; using 3403 reflections.

In Section 3.4, crystal and molecular structure studies of flunarizinium nicotinate (V), is reported. In the cation of the title salt $C_{26}H_{27}F_{2}N_{2}^{+}.C_{6}H_{4}NO_{2}^{-}$, the piperazine ring is in a slightly distorted chair conformation. In flunarizinium nicotinate, the two ionic components are linked by a short charge-assisted $\text{N}--\text{H}···\text{O}$ hydrogen bond. The ion pairs are linked into a three-dimensional framework structure by three independent $\text{C}--\text{H}···\text{O}$ hydrogen bonds, augmented by $\text{C}--\text{H}···(\text{arene})$ hydrogen bonds and an aromatic $\pi--\pi$ stacking interaction. The title compound (V), crystallizes in a monoclinic space group $Pc$ and cell constants $a = 10.8536(4)$ $\text{Å}$, $b = 10.8103(4)$ $\text{Å}$, $c = 11.3901(4)$ $\text{Å}$, $\beta = 92.717(2)^\circ$, $V = 1334.91(8)$ $\text{Å}^3$, and $Z = 2$ at 200 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final $R_1 = 0.027$ and $wR_2 = 0.081$; using 6092 reflections.

In Section 3.5, crystal and molecular structure studies of flunarizinium succinate (VI), is reported. In the title salt, $C_{26}H_{27}F_{2}N_{2}^{+}.C_{4}H_{5}O_{4}^{-}$, the piperazine N atom bearing the vinylic substituent is protonated. The piperazine ring adopts a chair conformation. In their crystal, the succinate monoanions are connected via short $\text{O}--\text{H}···\text{O}$ hydrogen bonds between the carboxylic acid and carboxylate groups into undulating chains extending along [001] and the flunarizinium monocations are attached to these chains via $\text{N}^{+}--\text{H}···\text{O}^{-}$ hydrogen bonds. $\text{C}--\text{H}···\text{O}$ interactions connect these chains into a three-dimensional network. The shortest centroid–centroid distance of 3.7256 (10) $\text{Å}$ was found between one of the fluorinated benzene rings and the nonfluorinated phenyl ring in the neighbouring molecule related by a glide plane. The title salt (VI), crystallizes in a monoclinic space group $Pc$ and cell constants $a = 10.7824 (2)$ $\text{Å}$, $b = 10.6270 (2)$ $\text{Å}$, $c = 11.2364 (2)$ $\text{Å}$, $\beta = 91.678 (1)^\circ$, $V = 1286.97 \text{Å}^3$, and $Z = 2$; $D_{\text{cal}} = 1.349 \text{Mg/m}^3$ at 200 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final $R_1 = 0.014$ and $wR_2 = 0.081$; using 3619 reflections.
In Section 3.6, crystal and molecular structure studies of flunarizinedium bis(4-toluenesulfonate) dihydrate (VII), is reported. In the cation of the title salt \(\text{C}_{26}\text{H}_{28}\text{F}_{2}\text{N}_{2}^{2+}\). \(2\text{C}_{7}\text{H}_{7}\text{O}_{3}\text{S}^{-}. 2\text{H}_{2}\text{O}\), the piperazine ring is in a slightly distorted chair conformation. In flunarizinedium bis(4-toluenesulfonate) dihydrate, one of the anions is disordered over two sites with occupancies of 0.832 (6) and 0.168 (6). The five independent components are linked into ribbons by two independent N—H···O hydrogen bonds and four independent O—H···O hydrogen bonds, and these ribbons are linked to form a three-dimensional framework by two independent C—H···O hydrogen bonds. The title salt (VII), crystallizes in a monoclinic space group \(P_{2_1}/c\) and cell constants \(a = 10.0546 (5) \text{ Å}, b = 14.8338 (6) \text{ Å}, c = 26.9437 (12) \text{ Å}, \beta = 106.497 (3)\)°, \(V = 3853.2 (3) \text{ Å}^3\), and \(Z = 4\) at 200 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final \(R_1 = 0.038\) and \(wR_2 = 0.202\); using 7212 reflections.

Chapter IV describes the preparation and crystal structure studies of Schiff bases of piperazine derivatives. Chapter IV is divided into four sections. Section 4.1 gives the introduction to Schiff bases of piperazines. In section 4.2, crystal and molecular structure studies of (4-methylpiperazin-1-yl)(2,3,4-trimethoxybenzylidene) amine (VIII), is reported. In the title compound, \(\text{C}_{15}\text{H}_{23}\text{N}_{3}\text{O}_{3}\), the piperazine ring is in a slightly distorted chair conformation and is twisted from the mean plane of the benzene ring making a dihedral angle of 14.94 (6)°. The 4-methoxy substituent is almost co-planar with the benzene ring [C—C—O—C torsion angle = 5.4(1)°], while the methoxy groups at positions 2 and 3 [C—C—O—C torsion angles of 122.6(4) and -66.1(4)°, respectively] are twisted away from the mean plane of the benzene ring in anticlinical and synclinical conformations, respectively. No classical hydrogen bonds or any weak intermolecular interactions are observed in the crystal structure. The title compound (VIII), crystallizes in the orthorhombic space group \(P_{b}c_{a}\) with cell constants \(a = 7.84207(14) \text{ Å}, b = 14.2305(3) \text{ Å}, c = 27.6218(5) \text{ Å}, V = 3082.49(10) \text{ Å}^3\), and \(Z = 8\); \(D_{\text{cal}} = 1.264 \text{ Mg/m}^3\) at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final \(R_1 = 0.051\) and \(wR_2 = 0.113\); using 2978 reflections.

In Section 4.3, crystal and molecular structure studies of 4-methyl-N-(4-nitrobenzylidene)piperazin-1-amine (IX), is reported. In the title compound, \(\text{C}_{12}\text{H}_{16}\text{N}_{4}\text{O}_{2}\), the piperazine ring is in a slightly distorted chair conformation. In the
molecule, the mean plane of the nitro group is twisted by 8.0 (3)° from that of the benzene ring. Also, the mean plane of the 2-nitrobenzyl ring is twisted slightly from that of the piperazine ring, with an N—N=C—C torsion angle of -176.24 (11)°. In the crystal, pairs of weak C—H···O interactions link the molecules into dimers approximately along [010]. The title compound (IX), crystallizes in a monoclinic space group \( C2/c \) and cell constants \( a = 27.9353 \) (14) Å, \( b = 5.9247 \) (3) Å, \( c = 18.7763 \) (7) Å, \( \beta = 126.527 \) (3)°, \( V = 2497.2(2) \) Å\(^3\), and \( Z = 8; \text{Dcal} = 1.321 \) Mg/m\(^3\) at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final R1 = 0.031 and wR2 = 0.119; using 2439 reflections.

In Section 4.4, crystal and molecular structure studies of N-(1H-indol-3-ylmethylidene)-4-methylpiperazin-1-amine (X), is reported. In the title compound, C\(_{14}\)H\(_{18}\)N\(_4\), the piperazine ring is in a slightly distorted chair conformation. The indole ring system is twisted from the piperazine ring, making a dihedral angle of 7.27 (11)°. In the crystal, N—H···N hydrogen bonds link molecules into chains along [101]. The title compound (X), crystallizes in a monoclinic space group \( Pn \) and cell constants \( a = 7.5630(5) \) Å, \( b = 6.5593(4) \) Å, \( c = 13.2319(9) \) Å, \( \beta = 100.072 \) (6)°, \( V = 646.29(7) \) Å\(^3\), and \( Z = 2; \text{Dcal} = 1.245 \) Mg/m\(^3\) at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final R1 = 0.050 and wR2 = 0.163; using 3857 reflections.

Chapter V describes the preparation and crystal structure studies of Schiff bases of piperazine derivatives. Chapter V is divided into five sections. Section 5.1 gives the introduction to 1-piperonylpiperazine. In section 5.2, crystal and molecular structure studies of 1-piperonylpiperazinium 4-chlorobenzoate (XI), is reported. In the title salt, C\(_{12}\)H\(_{17}\)N\(_2\)O\(_2\).C\(_7\)H\(_4\)ClO\(_2\), the piperazine ring adopts a slightly disordered chair conformation. The dioxole ring is in a flattened envelope conformation with the methylene C atom forming the flap. The relative orientation of the piperonyl ring system and the piperazine rings is reflected in the N—C—C—C torsion angle of 132.3 (1)°. In the anion, the mean plane of the carboxylate group is twisted from that of the benzene ring by 14.8 (9)°. In the crystal, the components are linked by N—H···O and weak C—H···O hydrogen bonds, forming chains along [010]. The title compound (XI), crystallizes in a monoclinic space group \( P2_1/c \) and cell constants \( a = 16.9967(6) \) Å, \( b = 8.5990(3) \) Å, \( c = 12.4150(5) \) Å, \( \beta = 90.923(3) \)°, \( V = 1814.27 \) (12)
Å\(^3\), and \(Z = 4\); Dcal = 1.380 Mg/m\(^3\) at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final R1 = 0.033 and wR2 = 0.120; using 2134 reflections.

In **Section 5.3**, crystal and molecular structure studies of 1-piperonylpiperazinium 4-nitrobenzoate monohydrate (XII), is reported. In the title hydrated salt, \( \text{C}_{12}\text{H}_{17}\text{N}_2\text{O}_2^+ \cdot \text{C}_7\text{H}_4\text{NO}_4^− \cdot \text{H}_2\text{O} \), the piperazinium ring of the cation adopts a slightly distorted chair conformation. The piperonyl and piperazine rings are rotated with respect to each other with an N—C—C—C torsion angle of 45.6 (2)º. In the anion, the nitro group is almost coplanar with the adjacent benzene ring, forming a dihedral angle of only 3.9 (4)º. In the crystal, the cations, anions and water molecules are linked through N—H···O and O—H···O hydrogen bonds into chains along a-axis. In addition, weaker intermolecular C—H···O interactions are also observed within the chains. The anions form centrosymmetric couples through π-stacking interactions, with an intercentroid distance of 3.681(4)Å\(^3\) between the benzene rings. The title compound (XII), crystallizes in a triclinic space group \(P_1\) and cell constants \(a = 6.0745\) (5) Å, \(b = 12.0617\) (11) Å, \(c = 13.4817\) (10) Å, \(α = 92.561\) (7)º, \(β = 98.753\) (7)º, \(γ = 93.326\) (7)º, \(V = 973.20\) (14) Å\(^3\), and \(Z = 2\); Dcal = 1.383 Mg/m\(^3\) at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final R1 = 0.021 and wR2 = 0.120; using 3761 reflections.

In **Section 5.4**, crystal and molecular structure studies of 1-piperonylpiperazinium 4-nitrobenzoate monohydrate (XIII), is reported. In the cation of the title salt [systematic name: 4-(2 H-1,3-benzodioxol-5-ylmethyl)piperazin-1-ium 2,4,6-trinitrophenolate], \( \text{C}_{12}\text{H}_{17}\text{N}_2\text{O}_2^+ \cdot \text{C}_6\text{H}_2\text{N}_3\text{O}_7^− \), the piperazine ring adopts a slightly disordered chair conformation. The piperonyl ring system and the piperazine ring are twisted with respect to each other with an N—C—C—C torsion angle of 40.7 (2)º. In the anion, the dihedral angles between the mean planes of the nitro substituents ortho to the phenolate O atom and the mean plane of the phenyl ring are 28.8 (9) and 32.2 (8)º. In contrast, the nitro group in the para position lies much closer to the aromatic ring plane, subtending a dihedral angle of 3.0 (1)º. In the crystal, the cations and anions interact through N—H···O hydrogen bonds and a weak C—H···O interaction. Weak C—H···O interactions are also observed between the anions, forming \(R_2^2(10)\) graph-set ring motifs. In addition, a weak centroid–centroid π–π stacking interaction between the aromatic rings of the cation and the anion, with an intercentroid distance
of 3.7471 (9) Å, contributes to the crystal packing, resulting in a two-dimensional network along (101). The title compound (XIII), crystallizes in a monoclinic space group $P2_1/n$ and cell constants $a = 12.0864$ (2) Å, $b = 6.96981$ (11) Å, $c = 23.4898$ (4) Å, $\beta = 96.5141$ (17)$^\circ$, $V = 1965.99$ (6) Å$^3$, and $Z = 4$; $D_{cal} = 1.518$ Mg/m$^3$ at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final $R_1 = 0.033$ and $wR_2 = 0.121$; using 3837 reflections.

In Section 5.5, crystal and molecular structure studies of bis{4-[(1,3-benzodioxol-5-yl)methyl]piperazin-1-yl}methane (XIV), is reported. In the title compound, C$_{25}$H$_{32}$N$_4$O$_4$, both piperazine rings adopt a chair conformation. One of dioxolane ring systems is essentially planar [dihedral angle = 0.9 (2)$^\circ$] while the other adopts a slightly disordered envelope conformation, the mean plane of the dioxolane ring being twisted by 3.6 (2)$^\circ$ from that of the benzene ring. The dihedral angle between the benzene rings is 69.9 (5)$^\circ$. No classical hydrogen bonds were observed. The title compound (XIV), crystallizes in a orthorhombic space group $Pn_2_1$ and cell constants $a = 38.8025$ (10) Å, $b = 9.7675$ (2) Å, $c = 9.7675$ (2) Å, $V = 2310.29$ (10) Å$^3$, and $Z = 4$; $D_{cal} = 1.312$ Mg/m$^3$ at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final $R_1 = 0.046$ and $wR_2 = 0.108$; using 4199 reflections.

Chapter VI describes the preparation and crystal structure studies of salts of 1-((4-chlorophenyl)(phenyl)-methyl)piperazine. Chapter VI is divided into two sections. Section 6.1 gives the introduction to 1-((4-chlorophenyl)(phenyl)methyl)piperazine. In section 6.2, crystal structures and DFT molecular orbital surface calculations of two new salts of 1-((4-chlorophenyl)(phenyl)-methyl)piperazine 4(C$_{17}$H$_{20}$ClN$_2$)$_+$.2(C$_4$H$_5$O$_4$)$^-$.(C$_4$H$_4$O$_4$)$_2$.H$_2$O (XV) and 2(C$_{17}$H$_{20}$ClN$_2$)$_+$.C$_6$Cl$_2$O$_4^-$.3(H$_2$O) (XVI) is reported. Complex (XV) crystallizes in the triclinic space group $P_1$, with $Z = 2$ in cells with $a = 9.6834(6)$ Å, $b = 16.9920(8)$ Å, $c = 24.9813(13)$ Å, $\alpha = 98.265(4)^\circ$, $\beta = 90.327(4)^\circ$, $\gamma = 105.929(5)^\circ$, $V = 3907.1(4)$ Å$^3$ and displays $R_4^4[12]$ ring motifs formed by hydrogen bonds and weak $\pi$-ring intermolecular interactions which contribute to the crystal packing forming a 2D network along (0 0 1). Complex (XVI) crystallizes in the monoclinic space group $C2/c$, with $Z = 8$ in cells with $a = 28.9941(7)$ Å, $b = 17.7719(9)$ Å, $c = 15.9647(10)$ Å, $\beta = 98.948(6)^\circ$, $V = 8126.2(8)$ Å$^3$ and displays bifurcated three center hydrogen bonds involving two of the three water molecules in the asymmetric unit.
and weak π–π and π-ring intermolecular interactions which pack the molecules into a 2D network along (1 0 0).

Chapter VII describes the preparation and crystal structure studies of some piperazine derivatives. Chapter VII is divided into six sections. Section 7.1 gives the introduction to piperazine derivatives. In section 7.2, crystal and molecular structure studies of 1-[4-(4-hydroxyphenyl)piperazin-1-yl]ethanone (XVIII), is reported. In the title compound, C_{12}H_{16}N_{2}O_{2}, the piperazine ring has a chair conformation. The dihedral angle between the mean planes of the benzene ring and the acetyl group is 48.7(1)°. In the crystal, molecules are linked via O—H···O hydrogen bonds, forming chains propagating along [010]. The title compound (XVIII), crystallizes in a monoclinic space group P2_{1}/c with cell constants a = 6.13183(19) Å, b = 12.0106(4) Å, c = 14.8704 (5) Å, β = 94.025 (3)°, V = 1092.46 (6) Å³, and Z = 4; Dcal = 1.339 Mg/m³ at 173(2) K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final R1 = 0.0405 and wR2 = 0.113; using 2134 reflections.

In section 7.3, crystal and molecular structure studies of 4-(furan-2-carbonyl)piperazin-1-ium 3,5-dinitrobenzoate (XIX), is reported. In the cation of the title salt, N—H···O the piperazine ring adopts a slightly distorted chair conformation. Twofold rotational disorder is exhibited by the furan ring in a 0.430 (4) : 0.570 (4) ratio. In the crystal, N—H···O hydrogen bonds link the ions into chains along [010]. Additional weak C—H···O interactions are observed, leading to a supramolecular layer parallel to (011). The title compound (XIX), crystallizes in orthorhombic space group Pbc a and cell constants a = 9.6060 (2) Å, b = 10.4572 (2) Å, c = 33.8766 (7) Å, V = 3402.97 (13) Å³, and Z = 8; Dcal = 1.532 Mg/m³ at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final R1 = 0.079 and wR2 = 0.123; using 3352 reflections.

In section 7.4, crystal and molecular structure studies of 4-acetyl(piperazinium) picrate (XIX), is reported. In the title salt, C_{6}H_{13}N_{2}O^{+}.C_{6}H_{2}N_{3}O_{7}⁻, the piperazinium ring has a slightly distorted chair conformation. In the picrate anion, the mean planes of the two o-NO₂ and p-NO₂ groups are twisted with respect to the benzene ring by 15.0 (2), 68.9 (4) and 4.4 (3)°, respectively. In the crystal, N—H···O hydrogen bonds are observed, linking the ions into an infinite chain along [010]. The title compound (XIX), crystallizes in a orthorhombic space group Pbc a and cell constants a =
6.6843(7) Å, \( b = 11.5971(12) \) Å, \( c = 20.131(2) \) Å, \( V = 1560.5(3) \) Å\(^3\) and \( Z = 4; \) \( \) \( \text{Dcal} = 1.521 \) Mg/m\(^3\) at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final \( R_1 = 0.036 \) and \( wR_2 = 0.126; \) using 9739 reflections.

In section 7.5, crystal and molecular structure studies of olanzapinium dipicrate (XX), is reported. The asymmetric unit of the title salt \( \text{C}_17\text{H}_{22}\text{N}_4\text{S}_2^+\cdot 2\text{C}_6\text{H}_2\text{N}_3\text{O}_7^- \), consists of a diprotonated olanzapinium cation and two independent picrate anions. In the cation, the piperazine ring adopts a distorted chair conformation and contains a positively charged N atom with quaternary character and the N atom in the seven-membered 1,5-diazepine ring, which adopts a boat configuration, is also protonated. The dihedral angle between the benzene and thiene rings flanking the diazepine ring is 58.8 (1)°. In one of the picrate anions, a nitro group is disordered over two sets of sites in a 0.748 (5) : 0.252 (5) ratio, and the benzene ring has a flat envelope conformation with the O−C atom displaced from the mean plane of the other five C atoms [maximum deviation 0.0151 (14) Å] by 0.1449 (14) Å. In the crystal, N−H···O hydrogen bonds and weak intermolecular C−H···S and C−H···O interactions link the components, forming a three-dimensional network. The title compound (XX), crystallizes in orthorhombic space group \( \text{Pbca} \) and cell constants \( a = 22.1660(4) \) Å, \( b = 12.7349(2) \) Å, \( c = 23.3951(4) \) Å, \( V = 6604.04(19) \) Å\(^3\) and \( Z = 8; \) \( \) \( \text{Dcal} = 1.550 \) Mg/m\(^3\) at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final \( R_1 = 0.041 \) and \( wR_2 = 0.107; \) using 6524 reflections.

In section 7.6, crystal and molecular structure studies of 1-(3-chlorophenyl)piperazin-1-ium picrate–picric acid (2/1) (XXI), is reported. The title salt, \( 2\text{C}_{10}\text{H}_{14}\text{ClN}_2^+\cdot 2\text{C}_6\text{H}_2\text{N}_3\text{O}_7^-\cdot \text{C}_6\text{H}_3\text{N}_3\text{O}_7 \), crystallized with two independent 1-(3-chlorophenyl)piperazinium cations, two picrate anions and a picric acid molecule in the asymmetric unit. The six-membered piperazine ring in each cation adopts a slightly distorted chair conformation and contains a protonated N atom. In the picric acid molecule, the mean planes of the nitro groups in the ortho-, meta-, and para-positions are twisted from the benzene ring by 31.5(3), 7.7(1), and 3.8(2)°, respectively. In the anions, the dihedral angles between the benzene ring and the ortho-, meta-, and para-nitro groups are 36.7(1), 5.0 (6), 4.8(2)°, and 34.4(9), 15.3(8), 4.5(1)°, respectively. The nitro group in one anion is disordered and was modeled
with two sites for one O atom with an occupancy ratio of 0.627(7) : 0.373(7). In the crystal, the picric acid molecule interacts with the picrate anion through a trifurcated O—H···O four-centre hydrogen bond involving an intramolecular O—H···O hydrogen bond and a weak C—H···O interaction. Weak intermolecular C—H···O interactions are responsible for the formation of cation–anion–cation trimers resulting in a chain along [010]. In addition, weak C—H···Cl and weak π–π interactions [centroid–centroid distances of 3.532(3), 3.756(4) and 3.705(3) Å] are observed and contribute to the stability of the crystal packing. The title compound (XXI), crystallizes in a monoclinic space group $Pc$ with cell constants $a = 11.2213$ (6) Å, $b = 14.6239$ (7) Å, $c = 14.1804$ (8) Å, $V =2253.8(2)$ Å$^3$ and $Z = 2$; Dcal = 1.592 Mg/m$^3$ at 173 K. The structure was solved by direct methods and refined by full-matrix least-squares procedures to final $R_1 = 0.035$ and $wR_2 = 0.139$; using 13782 reflections.

On the whole, the entire work presented in the thesis provides valuable information about crystal and crystal structure studies of piperazine derivatives which have wide application in various field of chemistry and in pharmaceutical industry. Based on the above experimental investigations, nineteen research papers have been published in International journals.

The literature survey for the present work is till to-date. The references have been arranged alphabetically at the end of every chapter in the thesis.