Chapter - V

ELECTRICAL CONDUCTIVITY
The remarkable growth of interest in the physics and chemistry of the organic solid state is reflected by a steady increase in the number of published investigations dealing with various aspects of this subject. Research on the organic solid state is increasingly being recognized as an inter-disciplinary field of study that combines related work not only by chemists and physicists, but also by electrical engineers, biologists and even medical researchers. While some of the initial impetus for such research has no doubt been stimulated by the progress that has been achieved from the study of the solid state properties of inorganic materials, particularly in the field of organic solid state science, it now stands on its own feet, so to speak. The theoretical and practical consequences of studies of the organic solid state cannot as yet be clearly ascertained and they may not necessarily follow the route set by the inorganic solid state [1]. Semiconducting organic solid materials are frequently grouped into the categories of molecular crystals, charge transfer complexes and polymers. Inorganic semiconductors stand on the threshold of a bright and exciting future. An organic semiconductor can be synthesized with properties comparable to those exhibited by inorganic semiconductor materials, such as development for transistors and the wide array of now-existing derivative devices and components of the electronics industry.

Widespread interest in the electrical conduction properties of metal complexes is a fairly recent phenomenon. It was realized that for conduction to occur in a complex it is necessary for there to be some form of electronic, as opposed to magnetic, interaction between either the metal atoms alone or the complexes as a whole in the lattice. The presence of an interaction of this type is revealed by the presence of strong absorption bands at lower energies than those present in the isolated metal complexes in solution. However, the presence of new intense absorption bands in the solid state does not necessarily promise high electrical conductivity, but in the absence of these additional absorptions the
complex is most likely to be an insulator. For high conductivity to be present the interaction between the metal atoms of complexes must extend throughout the solid and not to be restricted to the dimer or cluster formation, since the spaces in the lattice between the delocalized clusters will be insulating. In coordination compounds as opposed to simple compounds it is very difficult to envisage interactions leading to conduction pathways in three dimensions and, therefore, the complexes with unusual electrical properties are anisotropic. By far the most common types are systems known as 'one-dimensional conductors'. This is a reflection of the common building block, a square coplanar complex, found for this class of compound.

For significant electrical conductivity in a metal complex there has to be the correct combination of both structural and electronic features.

(i) **Structural**:

The shape of the complex must be such that extensive intercomplex interactions can occur in the solid state. For this reason, columnar stacked structures involving square coplanar complexes and allowing effective intrastack interactions are most commonly found in compounds of this type. Electron transport will be facilitated by the close approach of the complexes and therefore the absence of bulky non electroactive ligands is an advantage. Detailed structural studies have shown the importance of interstack interactions (e.g. hydrogen bonding, ligand-ligand bonding) in stabilizing these structures, and these interactions can also have an important bearing on the electrical conduction properties.

(ii) **Electronic**:

Complexes can conveniently be divided into those that show only semiconductor-type behaviour, and those that show metallic behaviour, possibly restricted to a certain temperature range. Semiconductors are characterized by
relatively low conductivities and a positive temperature dependence of the conductivity, and most complexes which exhibit detectable electrical conductivity belong to this class. In general, this type of behaviour is found for complexes containing metal ions in integral oxidation states.

In columnar stacked one-dimensional complexes, such as the tetracyanoplatinates, with relatively short intrachain Pt-Pt separations, it is possible to postulate a simple band model by considering overlap of the filled 5dz^2 orbitals on individual atoms in the chain to produce a full 5dz^2 band, and overlap of the empty 6pz orbitals to produce an empty 6pz band (Fig. 5.1).

![Diagram](image)

**Fig. 6.1:** Representation of the band formation in a columnar stack structure. (A) semiconductor based on integral oxidation state d^9 complex. (B) One-dimensional metal produced by partial oxidation and resulting in a 'non-integral' oxidation state.
The intrinsic band gap is too great to account for the observed conductivities and the presence of PtIV impurities, which creates acceptor levels within the band gap, has been found in related systems. The temperature dependence of the conductivity as given by

$$\sigma = \sigma_0 \exp \left[ - \frac{\Delta E}{kT} \right]$$

where, $\sigma$ is the conductivity, $\sigma_0$ is a constant and $\Delta E$ is the activation energy is often obeyed for these systems.

An alternative model considers the carriers to be localized on individual molecules and that charge transfer occurs by the carrier hopping between these localized centres. The hopping process involves the charge carrier overcoming a potential energy barrier and thus involves an activation energy for conduction. The temperature dependence of this conductivity may depend on the dimensionality of the system.

The coordination compounds are well known for their behaviour as semiconductors. The systematic investigation of the semiconducting behaviour was first developed by Brattain and Garrett [2]. The electrical conductivity of some complexes and polychelates derived from organic compounds play an effective role in the conduction process. Increase in the conductivity values of organic compounds was observed owing to the inclusion of metal ions into the $\pi$ electron delocalization of organic compounds [3,4]. The reduction in conductivity values was also observed which is attributed to the localized bond between metal and organic compound [5,6].

In most of metal complexes of bi or polychelate ligands, for easy conduction throughout the polychelate, each metal ion must provide a conduction path for $\pi$-electrons from one adjacent ligand to the other. This will be the case if the ligands are coplanar and the metal ion forming $d\pi-p\pi$ bonds to both ligands by using the same $d$-orbital. This, in turn, requires that the ligands should be of
chelating type and that the metal ion forms either square planar chelate or octahedral chelate with the same kind of ligands occupying the sites trans to one another. In case of tetrahedral complexes where the ligands are cis to one another, though conjugation is unimportant, the central atom seems to prefer to use different d-orbitals to form π-bonds with the different ligands as the use of single d-orbital for this purpose being geometrically unfavourable. In order to ensure co-planarity, it is almost essential to use chelating ligands and to arrange them about the metal in a square coplanar array. This has the further advantage of enabling the metal to use two d-orbitals for π-bonding. Thus if the ligands lie in the XY plane, the dxz and dyz orbital of the metal will be ideally placed in such a way that both these orbitals can form π-bonds simultaneously with these two ligands. This in turn require the metal to be either one forming square coplanar complex or octahedral complexes with two trans positions blocked by ligands of some other type. Clearly, the former alternative is more preferable.

The electrical conductivity of organic compounds is an important physical property. Organic conductors have high number of unsaturated C=C bonds forming conjugated system. It is known that the π electrons of such system are not bound to definite carbon atoms but are capable of moving over the entire molecule. That is why these may be showing semiconducting behaviour. The conductivity values also depend on the number of conjugated system present in the compound, increase in aromaticity i.e. the resonance, mesomeric and inductive effects of the substituents etc. [7]. It is known that the presence of an electron donating group increases the electron density of the conjugated system leading to an increase in the electrical conductivity, relative to the presence of the electron withdrawing group, which withdraws the electron cloud from such system.

The main drawback of organic semiconductor is its low carrier mobility due to lack of an ordered structure in such materials. The electrons get
scattered while travelling through such materials and hence the conductivity is lowered. The conduction due to transfer of charges from one molecule to another takes place through overlapping of neighbouring molecules. For broad intermolecular potential barriers, the overlap is poor and the band width is narrow. In this case, the charge carriers can jump from one molecule to the neighbouring molecule [8]. With this assumption of jumping or hopping mechanism, the mobility of charge carrier is very low [9]. In order to overcome these difficulties, many chelates have been synthesized in which transition metals have been used to bridge the ligand molecules, particularly with aromatic group, through conjugation. This makes the dπ-π interaction with the adjacent ligand possible through the d-orbitals of the metals. The π-network facilitates the electrical conductivity.

**Literature Survey:**

In recent years, the investigations on the electrical conduction mechanism in organic compounds have been much intensified [10]. This is mainly due to attracting properties of organic semiconductor for the technology of solid state devices [11-13]. Electrically conducting and semiconducting organic compounds have been a subject of extensive studies in view of both academic interest and potential technological applications [14]. Organic semiconductors can conduct charges due to partial delocalization or charge hopping through the molecules [8,15,16]. A number of organic-based PV cells, including organic/inorganic hybrid configurations, have been investigated [17-19]. However, during last two decades, a significant international research efforts have been made by several workers, as a result of search for high quality inorganic semiconductors. In the fitness of the present investigation, relevant literature is presented in the following paragraphs.
The solid state AC electrical conductivity of the VO(IV) Schiff base complexes [20] in compressed pellet form (3 ton cm⁻²) measured at room temperature showed the values in the range 1.49 x10⁻⁴ - 8.26 x10⁻⁴ S cm⁻¹ suggesting the semiconducting nature of the complexes. Singh and Kushawaha [21] studied the electrical conductivity of VO(IV), Fe(III), Cd(II), Cu(II) and Zn(II) complexes of N-isonicotinoyl-N'-p-hydroxy thiobenzhydrazine and reported low value of σₚ in the range of 10⁻¹ - 10⁻⁹ S cm⁻¹. The conductivity of all the complexes except VO(IV) was found to increase as temperature increases from 307-397 K with a band gap of 0.12-0.95 eV indicating their semiconducting behaviour.

The electrical conductivity of N-phenyl-3-carboethoxy-4-methyl-5-cyanopyridazin-6-one and its Cr(III), Mn(II), Fe(III), Co(II), Ni(II) and Cu(II) complexes have been studied by Hassan et al [22]. All the samples behaved as semiconductors. The delocalized d-orbital electrons contributed as charge carriers. The conductivity showed a tendency to increase with the rising of temperature. The lower temperature range was the region of the extrinsic semiconductors, whereas the higher temperature range was the region of intrinsic semiconductors. The activation energy was linearly dependent on the ionic radius. El-Manakhly [23] studied the electrical conductivity of the cationic exchanged Co(II), Fe(II)-Cu(II)-Y-zeolite and correlated the electrical conductivity data with the electronic structures, state of the cations and the properties of these catalysts, which exhibit different semiconducting behaviour. Singh et al [24] carried out d.c. electrical conductivity measurement of sugar and compressed pellets in which Fe₂O₃ was introduced as an impurity. Temperature dependence of conductivity of this material characterizes it to be a semiconductor. The observed activation energy seems to suggest protonic conduction mechanism which is attributed to the protons of hydrogen bond network which is thought to be responsible for the observed activation energy.
(0.20 - 0.40 eV) lies in the range of hydrogen bond energy (0.20 - 0.30 eV). The complex heterobimetallic salts derived from 1-ethoxycarbonyl-1-cyanoethylene-2,2-dithiolatodioxouranate (VI) ion exhibited room temperature conductivity in the range $2.80 \times 10^{-13}$-$1.93 \times 10^{-3}$ $\Omega^{-1} \text{cm}^{-1}$ and showed semiconducting behaviour as their $\ln \sigma$ values decreased with $1/T$ in the temperature range (303-373 K) with an activation energy between 0.052 and 1.007 eV [25].

Kamal et al [26] studied the semiconductor properties of metal complexes of Mn(II), Cr(II), Co(II), Ni(II), Cu(II) and Fe(III) with anthraquinone-o-carboxylic phenyl hydrazone and conductivity shows increasing tendency by raise of temperature. The lower temperature range is the region of extrinsic semiconductors, where the conduction is due to the excitation of carriers from donor localized level to the conduction band. At the upper temperature range, the intrinsic region is reached where carriers are thermally activated from the valence band to the conduction band [27]. This behaviour can be attributed to interaction between the electrons of metal d-orbitals and $\pi$-orbitals of the ligand at upper temperature range [28].

Pancholi and Patel [29,30] have reported the polychelates of Cu(II), Ni(II), Co(II), Mn(II), Zn(II), VO(IV) and UO$_2$(VI) with 2-hydroxy-acetophenone oxime-thiourea-trioxane and 2,4-dihydroxy-acetophenone oxime-thiourea-trioxane. The complexes of anthraquinone-o-carboxylic phenyl-hydrazone with Cr(III), Mn(II), Fe(III), Ni(II) and Cu(II) metal ions were synthesized and their electrical conductivity was measured [31]. The electrical conductivity of these complexes at 298 K decrease in the order: Fe(III) > Cr(III) > Mn(II) > Ni(II) > Cu(II). The temperature-dependence of electrical conductivity data reveals a linear trend with inflections appearing at different positions. The values of electrical conductivity lie in the range ($4.81 \times 10^{-11}$ - $5.30 \times 10^{-10}$ ohm$^{-1}$ cm$^{-1}$) of typical semiconductors [32]. The break observed in plots indicates the presence of a phase transition, i.e. two different conduction
processes with two activation energies. The phase transition observed for a ligand is most probably associated with two molecular structures (keto-enol form) which exchange the conduction at different thermal stabilities [33]. On the other hand, it is known that increasing of complex stability results in decreasing conductivity due to a decrease in π-electron mobility [34]. The conductivity at 298 K follows the order Fe(III) > ligand > Cr(III) > Mn(II) > Ni(II) > Cu(II), obeying Irving-Williams series except Fe(III) complexes.

The electrical properties of some Schiff base complexes of Cu(II), Zn(II), Hg(II), Pb(II), Rb(II) and UO₂(VI) with N-(2-hydroxy) benzilidene-β-alanine have been studied by Ahmed et al [35]. The observed electrical conductivities were found in the range 1 x 10⁻⁸ to 5.495 x 10⁻⁸ Ω⁻¹ cm⁻¹ at lower temperature and 1.77 x 10⁻⁵ to 4.169 x 10⁻⁸ Ω⁻¹ cm⁻¹ at higher temperature. Maruyama et al [36] studied the electrical conductivity of (2,2'-bipyridine-5,5'-dil) by using Ni(O) complexes. Patel et al [37-43] have carried out the electrical measurements of Schiff base coordination polymer of transition metal ions and inferred that the low value of electrical conductivity may be due to the low molecular weight and undesirable morphology occurring during the preparation of the pellets; furthermore, the low magnitude of activation energy may be due to the presence of a large number of π-electrons. The electrical conductivities of some of the bimetallic salts Ni(II), Fe(II), Cu(II), Zn(II), Cd(II), Co(II) and Ru(II) with bipyridyl, phenanthroline or ethylene-diamine and malonyl 1,2-ethylene dithiolate have been studied by Singh and Prasad [44] in the temperature range 32-120°C. Electrical conductivities (3 x 10⁻⁸-3 x 10⁻⁶ ohm⁻¹ cm⁻¹) of compacted samples show that all the complex salts exhibit semiconducting behaviour at room temperature.

Aswar et al [45-57] have extensively studied the semiconducting properties of a large number of Schiff base ligands and their chelates/ polychelates with transition metal ions. The electrical conductivity of the
polychelates of Cr(III), Mn(III), Fe(III), Ti(III), VO(IV), Th(IV), Zr(IV) and UO₂(VI) with bis-bidentate Schiff base derived from 4,4'-bis [(salicylaldehyde-5)-azo] diphenyl methane and aniline have been studied over the temperature range 313-493 K [45]. The activation energy of the electrical conduction lies in the range 0.912 to 0.315 eV and the chelates are found to show semiconducting behaviour. The phase transition in case of the ligand may be attributed to two molecular structures having keto and enol forms which exchange the conduction at different thermal stabilities. The solid state electrical conductivity of the complexes of Cr(III), Mn(III), Fe(III) and Al(III) with Schiff bases derived from 2-hydroxy-5-methylacetophenone and 2-hydroxy-5-chloracetophenone with p-phenylene diamine were studied over a wide range of temperature [55]. The electrical conductivity (σ) varied exponentially with absolute temperature according to the relationship $\sigma = \sigma_0 \exp \left(-\frac{E_a}{kT}\right)$. The low value of electrical conductivity (9.1×10⁻⁸ - 4.4×10⁻⁹ Ω⁻¹ cm⁻¹) may be attributed to low molecular weight due to which the extent of conjugation becomes low or undesirable morphology occurs due to pressing of the sample into hard brittle pellet forms. The electrical conductivity and semiconducting properties of polymeric complexes of Co(II), Ni(II), Cu(II) and Zn(II) with Schiff base ligands bis-(2-hydroxy-5-methylacetophenone)-1,3-diaminopropane and bis-(2-hydroxy-5-chloracetophenone)-1,3-diaminopropane have been studied by Bahad et al [56]. The conductivity of chelates at 373 K follows the order Co > Zn > Cu and Zn > Co > Cu > Ni respectively. The chelates of Mn(II), Co(II), Ni(II), Cu(II), Zn(II) and Cd(II) with 4,4'-dihydroxy-3,3'-dipropyl biphenyl-o-phenylenediamine have been synthesized and studied their electrical properties [57]. The electrical conductivity of polychelates at room temperature declines in the order Co > Ni > Mn > Cu > Cd > Zn, while the activation energy of electrical conduction decreases in the order Mn > Zn > Co > Ni > Cd > Cu. The observed low values of activation energy may be attributed to the interaction between the electrons of the metal d-orbitals and π-orbitals of the ligand.
Thus literature survey revealed that most of the metal complexes and polychelates show semiconducting behaviour due to the presence of delocalised electrons and conjugation which impart semiconducting properties in them. A complete understanding of the relationship between the chemical structure of the complexes and their electronic and conduction properties and suitable chemical and structural modification of the complexes make them to behave as good electrical conductors intrinsically without the need of doping.

**Experimental:**

The electrical resistivity of the different metal chelates can be measured with either a.c. or d.e. method. However, in the present work d.c. method is used for resistivity measurements, over a wide range of temperature i.e. from room temperature to 403 K. The measurements involved following steps.

a) **Preparation of Pellets:**

In order to prepare the pellets, the Schiff bases and metal complexes were ground separately to 300 mesh size in an agate pestle and mortar. The well powdered compounds were pelletedized isostatically in a steel die of 13 mm diameter under a pressure of 5-6 tons cm\(^{-1}\) with the help of hydraulic press. The pellet thus obtained was crack-free and hard. The end faces of pellets were gently ground over a zero number emery paper to ensure smooth surfaces and desired polishing. A thin aluminium foil was used for the good electrical contact. The surface continuity of the pellet was then tested by means of a multimeter.

The average diameter of the pellet and its thickness were measured using screw gauze. Actual dimensions were measured as average of the three
measurements taken at three different places. The pellets were then stored in desiccator till needed for conductivity measurements.

b) **Sample Holder**:

A typical sample holder is specially designed and fabricated for the purpose of resistivity measurements. It consists of two brass electrodes, one of which is fixed to the asbestos plate by means of brass nuts. The other electrode is also fixed to the asbestos plate but which is spring loaded, which presses hard against the surface of the pellet.

c) **Furnace for heating the sample**:

For resistivity measurements at different temperatures, a suitable electrical furnace was constructed by winding the standard resistor kanthal wire over an alumina tube of 1.5 inch diameter and packing it with ceramic blanket in a tin box. Heating of the furnace was controlled with the help of dimmerstat. The current to the furnace was recorded by means of an a.c. ammeter. The accurate measurement of the temperature of the furnace was achieved and recorded by means of standard chromel-alumel thermocouple connected with Systronic digital multimeter Model No. 435 in which the emf developed in millivolts were measured. The measuring junction of the thermocouple and the pellet in the sample holder were at the same level, almost in the centre of the furnace where temperature was uniform. The connection wires of two electrodes which were insulated with porcelain beads were taken out for connections.

d) **Experimental Procedure**:

The resistance of pellet was measured by voltage drop method using a Systronic microvoltmeter as a function of temperature in the range 1 to 100 V. The connecting wires of sample holders from the furnace were connected to the two terminals of the instrument. In this way corresponding resistance (R) of the pellet was measured directly by keeping the pellet in sample holder.
\[ R = \left( \frac{V_T - V_R}{V_R} \right) \times 10^5 \, \Omega \]

where \( V_T \) = total voltage range applied.  
\( V_R \) = actual voltage across resistance  
\( R \) = resistance of the pellet.  

Resistivity \( (\rho) \) was then calculated using relation,  
\[ \rho = \frac{(R \times A)}{t} \]

where \( A \) = surface area of pellet  
\( t \) = thickness of pellet  

The electrical conductivity \( (\sigma) \) varies exponentially with the absolute temperature according to well known relation,  
\[ \sigma = \sigma_0 \exp (-E_a/kT) \]

where \( \sigma \) = electrical conductivity at temperature \( T \)  
\( \sigma_0 \) = electrical conductivity at temperature \( T = \infty \)  
\( E_a \) = activation energy of electrical conduction  
\( k \) = Boltzmann constant of electrical conduction  
\( T \) = absolute temperature.  

This relationship has been modified as,  
\[ \log \sigma = \log \sigma_0 + \left[ -\frac{E_a}{2.303 kT} \right] \]

According to this relation, a plot of \( \log \sigma \) vs \( 1/T \) would be linear, with negative slope, such plots were made on the basis of each set of data. The plots of temperature dependence of electrical conductivity of the ligands and their chelates have been drawn.
Results:

The measurement of d.c. electrical conductivity of all the Schiff base ligands and their chelates were carried out from room temperature to about 403 K. The results of electrical conductivity at 313 and 373 K and activation energy are incorporated in Table-5.1. The temperature dependence of the electrical conductivity of the ligands and their chelates are shown in figures 5.2 to 5.6. The following results have been drawn from the results of electrical conductivity measurements.

I. HCASTZ and its complexes:

The electrical conductivity and activation energy of HCASTZ and its complexes are cited in Table 5.1 and the temperature dependence of log σ of these compounds are shown in Fig. 5.2. It is observed that:

1. The plot of log σ vs. $10^3/T$ are found to be linear in measured temperature range 313-403 K [59].

2. Electrical conductivity of the compounds lies in the range of $4.90 \times 10^{-13}$ to $9.66 \times 10^{-11} \Omega^{-1} \text{ cm}^{-1}$ at 373 K.

3. The electrical conductivity of these compound at 373 K follows the order:
   
   \[
   \text{MoO}_2 > \text{Mn} > \text{UO}_2 > \text{VO} > \text{Ti} > \text{Zr} > \text{HCASTZ} > \text{Cr} > \text{Fe}
   \]

4. The activation energy of electrical conduction of the complexes lies between 0.136-1.081 eV and has been found to increase in the order:
   
   \[
   \text{Fe} < \text{Cr} < \text{Ti} < \text{MoO}_2 < \text{HCASTZ} < \text{Zr} < \text{VO} < \text{UO}_2 < \text{Mn}
   \]

II. DHATCH and its complexes:

The temperature dependence of electrical conductivity of DHATCH and its complexes reveals a linear trend (Fig. 5.3) and data is cited in Table 5.1. From the results it is observed that:

1. The electrical conductivity of DHATCH and its complexes shows a tendency to increase by raising the temperature up to 403 K.
2. The electrical conductivity of these compounds lies in the range $3.09 \times 10^{-12}$ to $7.01 \times 10^{-8}$ $\Omega^{-1}$ cm$^{-1}$ at 373 K.

3. The order of electrical conductivity of DHATCH and its complexes at 373 K is found to be Mn > VO > UO$_2$ > Ti > MoO$_2$ > Cr > Fe > Zr > DHATCH.

4. The activation energy of electrical conduction of these compounds lies between 0.177 - 0.708 eV and is found to increase in the order:

$$\text{Fe} < \text{Zr} < \text{Mn} < \text{DHATCH} < \text{Cr} < \text{Ti} < \text{VO} < \text{UO}_2 < \text{MoO}_2$$

III. **DHACHZ and its complexes**:

Temperature dependance of electrical conductivity of DHACHZ and its complexes are shown in Table 5.1 and Fig. 5.4. The results are summarized as below:

1. The electrical conductivity of DHACHZ and its complexes lies in the range $2.13 \times 10^{-12}$ to $5.05 \times 10^{-9}$ $\Omega^{-1}$ cm$^{-1}$ at 373 K.

2. The electrical conductivity of the compounds at 373 K decreases in the order: Ti > Cr > UO$_2$ > MoO$_2$ > VO > Fe > Zr > Mn > DHACHZ

3. The activation energy of electrical conduction of DHACHZ and its complexes lies between 0.376 - 1.056 eV and increases in the order:

$$\text{DHACHZ} < \text{Mn} < \text{Zr} < \text{MoO}_2 < \text{Fe} < \text{Cr} < \text{VO} < \text{Ti} < \text{UO}_2$$

4. Over a wide range of temperature, plots of $\log \sigma = f(\frac{1}{T})$ were found to be linear in the studied temperature range.

IV. **DHATSC and its complexes**:

The results of the electrical conductivity of DHATSC and its complexes (Table 5.1 and Fig. 5.5) are given as follows:

1. Plots $\log \sigma$ against reciprocal temperature are found to be linear.
2. The electrical conductivity at 373 K of the compounds has been found in the range \(1.97 \times 10^{12}\) to \(6.76 \times 10^{7} \ \Omega^{-1}\ cm^{-1}\).

3. The electrical conductivity of DHATSC and its complexes at 373 K declines in the order:

\[
\text{Mn} > \text{VO} > \text{Ti} > \text{DHATSC} > \text{MoO}_2 > \text{Cr} > \text{UO}_2 > \text{Fe} > \text{Zr}
\]

4. The activation energy of electrical conduction of these compounds lies between 0.305 - 0.944 eV and decreases in the order:

\[
\text{DHATSC} > \text{MoO}_2 > \text{UO}_2 > \text{Ti} > \text{Cr} > \text{VO} > \text{Zr} > \text{Mn} > \text{Fe}
\]

V. DHASCZ and its complexes:

The results of temperature dependence of electrical conductivity of DHASCZ and its complexes (Table 5.1 and Fig. 5.6) are summarized as follows:

1. The plots of \(\log \sigma vs 10^3/T\) are found to be linear.

2. The electrical conductivity of these compounds at 373 K is in the range \(1.31 \times 10^{12}\) to \(5.92 \times 10^{7} \ \Omega^{-1}\ cm^{-1}\).

3. The order of electrical conductivity of these compounds at 373 increases in the order: \(\text{Zr} > \text{Fe} > \text{DHASCZ} < \text{Cr} < \text{VO} < \text{Mn} < \text{MoO}_2 < \text{UO}_2 < \text{Ti}\).

4. The activation energy of electrical conduction of these compounds lies between 0.228 - 0.566 eV and is found to be increase in the order:

\[
\text{Zr} < \text{DHASCZ} < \text{Fe} < \text{Cr} < \text{Ti} < \text{Mn} < \text{UO}_2 < \text{VO} < \text{MoO}_2
\]

Discussion:

From the results of electrical conductivity of all the Schiff bases and their complexes under investigation the following conclusion can be drawn.

1. The electrical conductivity of all the Schiff base ligands and their complexes shows a tendency to increase by raising the temperature upto 403 K and obeys the relation \(\sigma = \sigma_0 \exp \left(-\frac{E_a}{kT}\right)\).
Fig. 5.3: Temperature dependence of log $\sigma$
References:


