# CHAPTER I

# INTRODUCTION

# CHAPTER I

## 1.1 SUPERCONDUCTIVITY

Superconductivity is practically a complete disappearance of electrical resistivity in certain metals (Lead, Zinc, Aluminum, etc.) and alloys (Bismuth and Gold, Carbides of molybdenum and Tungsten, Niobium nitride, etc.) at a certain transition temperature $T_C$, called the ***critical temperature***. A perfect superconductor is a material, which is, associated with two characteristic properties, namely zero electrical resistance and perfect diamagnetism. This perfect superconductivity is established when the material is cooled below $T_C$ [1].

It should be mentioned here that at higher temperatures the superconductor is found to be a normal metal, and ordinarily is not a very good conductor. For example, Lead, Tantalum, and Tin become superconductors, while Copper, Silver, and Gold, which are much better conductors, are not superconductors. Taking into account the sensitivity of modern equipment, one can argue that the resistivity of superconductors is zero, when it is of the order of $10^{-24}$ Ω cm. For comparison, one may note that the resistivity of high purity Copper is of the order of $10^{-9}$ Ω cm at 4.2 K [2].

Perfect diamagnetism, the second characteristic property, means that a superconducting material does not permit an externally applied magnetic field to penetrate inside the material. For as long as 22 years after the discovery of the superconductivity, scientists believed that a superconductor was simply an ideal conductor. But the experiment revealed that this was not true because of the magnetic properties of superconductor. Those superconductors that totally exclude an applied magnetic flux are known as ***type I*** superconductors. Other superconductors, called ***type II superconductors***, are also perfect conductors of electricity, but their magnetic properties are more complex. They totally exclude magnetic flux when the applied magnetic field is lower than $H_{C1}$ (*lower critical magnetic field*), but only partially exclude it when the applied field is higher [1-3].

## 1.2 THE DISCOVERY OF SUPERCONDUCTIVITY

In 1908, ***Onnes*** has succeeded in liquefying Helium in the vicinity of absolute zero (ca. 1K to 10K) in his laboratory at Leiden [4]. This was the first stage for the discovery of superconductivity. After three years, during his study on the variation of the electrical resistance of Mercury with temperature, he observed that the resistance dropped to zero at 4.2K.

This new phenomenon was known as superconductivity and the corresponding materials were called superconductors [3].

After two years, ***Onnes*** found that Lead becomes superconducting at 7.2K. The superconductivity phenomenon that detected later for some other materials: such as, Niobium, Tin, Indium, Aluminum and others. Many alloys, intermetallic compounds, organic materials, ceramics...etc., also turned out to be superconductors [1-2].

## 1.3 THE MAGNETIC PROPERTIES OF TYPE-I SUPERCONDUCTORS

Shortly after the discovery of superconductivity, ***Onnes*** discovered, in 1914, that this phenomenon can be destroyed not only by heating the sample, but also by placing it in a sufficiently strong magnetic field. This magnetic field is called the ***"critical field"*** of bulk material, which is labeled as $H_{cm}$ or ***"thermodynamic critical field"***. This critical field is zero at the critical temperature. In addition it is found that the critical field, in which superconductivity is destroyed, decreases with increasing temperature [5]. A strong electric current also destroys superconductivity. It is observable that if the superconductor is not too thin,

***the critical current*** $I_C$ at the surface of a superconductor must produce a magnetic field equals to ***the critical magnetic field*** $H_{cm}$ [3].

## *1.3.1 Messiner- Ochsenfeld Effect*

In 1933, ***W.Messiner*** and ***R. Ochsenfeld*** discovered that not only a magnetic field is excluded from entering a superconductor, as might appear to be explained by perfect conductivity, but also a field in an originally normal sample is expelled as it is cooled through $T_C$ [6, 7]. In the absence of any transport current one gets what is called the shielding or magnetization current density which is flowing around the surface layer of superconductor. At the same time it does not exist in the bulk of superconductor. It may be looked upon as a shielding or screening current shields or screens the interior of the superconductor by producing a negative magnetic field which in turn it cancels the applied magnetic field. This means that the magnetic field inside the sample is equal to zero [1]. The experiment was very important because it revealed that a superconductor is not an ideal conductor although it has a zero electrical resistance [3]. According to this, one can treat a transition to the superconducting state as a phase transition and, consequently, apply all the might of the thermodynamic approach to examine the superconducting phases [2].

consequently, apply all the might of the thermodynamic approach to examine the superconducting phases [2].

### *1.3.2 The Intermediate State*

Let us consider, for example, the behavior of a superconducting sphere in an external homogeneous magnetic field. It should be remembered that the effect of the magnetic field depends on the shape of the sample, i.e., depends on the demagnetization factor. Now for this case, the magnetic field lines are always tangential to the surface of superconducting sphere. Thus it is obvious that the field has a higher density at the 'equator'. While at the poles the magnetic field is zero, this means that at the equator the field is a maximum value and larger than external magnetic field. Supposing that the field at the equator is larger than ***the critical magnetic field*** $H_{cm}$, then the superconductivity vanished at the equator but the sample remains superconductor.

In 1936, Peierls [3,8] and London [3,9] solved this problem by introducing the idea of the ***"intermediate state"*** in the region of the external field:

$$(1-n)H_{cm} < H_o < H_{cm}$$

Where $H_o$ is the external magnetic field and $n$ is the demagnetization factor. In 1937 ***Landau*** carried out an investigation for the structure of this intermediate state [3,10]. He considered the laminar structure for the alternating normal and superconducting region. The interfaces between the superconducting and normal regions are always parallel to the external field, while the cross-sections of these regions are perpendicular to the field. In this state the electrical resistance becomes anisotropic because the resistance of the normal region is larger than the resistance of the superconducting region. For more details, The magnetic structure of a sphere in the intermediate state is discussed by P. R. Solomon and R. E. Harris [11,12], while ***L. D. Landau*** explained the intermediate state in an infinite flat slab [12,13]. Also classic experiments, to clarify the magnetic structure of a sphere in the intermediate state, were performed by A.I.Shalnikov and A.G.Meshkovskii [2,14,15].

## *1.4 LONDON THEORY*

From a theoretical point of view, much has been done, starting with the application of thermodynamics to the transition by W.H.Keesom as early as 1924 [16]. Following this in 1934 was a phenomenological explanation of the second-order transition and other properties based on a two-fluid model developed by C.J.Gorter and H.B.G.Casmir [16,17]. Phenomenological theory of the electrodynamics properties of superconductors has been established by ***F. London and H. London***, in 1935 [12,18]. The aim of this theory is to express, in a mathematical form, the basis of the following experimental facts namely, the absence of resistance and ***Messiner effect***. In addition, this theory is based on Maxwell equations and two additional equations called London equations. The first London's equation describes a conductor with zero resistance. In other words, this equation shows that the change of the current density with time is proportional to the electric field [4]. The second equation describes ***the Messiner-Ochesenfeld effect***. At the same time this theory led to the following important conclusions:

1- An external magnetic field penetrates a distance of order $\lambda_L$ into the superconductor, where $\lambda_L$ is known as a ***"London penetration depth"***. It is a measure of the decay of a magnetic field in the interior of a superconductor [19]. The experiments showed that $\lambda_L$ is lower than the observed penetration depth $\lambda$.

2- A supercurrent carried by ***'superelectrons'*** and a normal current carried by ordinary electrons coexist. When a superconductor carries a constant surface current, there can be no electric field within it and the normal electrons are not accelerated. It is useful to notice that the density of superelectrons is zero at ***critical temperature*** $T_C$, and is rising to a maximum value at 0 K. As the result of this situation $\lambda_L$ has a very large value at $T_C$ and it becomes a minimum at 0 K.

3- The theory predicted that superconductivity would arise if a fraction of electrons-***'the superelectrons'***-were in a condensed state of minimum momentum, and if the momentum is zero then by Heisenberg uncertainty principle the carrier wave function would have unlimited extent. On this basis ***London*** is able to show that if the wave function of these superelectrons remains unchanged in the presence of a weak magnetic field then ***superconductivity*** arises [14].

4- The quantization of a ***magnetic flux***, is associated with what is called the magnetic flux quantum number $\Phi_o$. In the ring or hallow superconducting cylinder, this magnetic flux is assumed to have values which are integral multiple of $\Phi_o$ [1-5].

***London theory*** is called a local theory because the supercurrent at a particular point is assumed to be controlled by the magnetic vector potential at the same position. Also this theory is restricted to states where the density of superconducting charges – ***say cooper pairs*** – can be assumed to be constant in the whole sample. It does not, therefore, cover ***the intermediate state*** [14,19]. Furthermore, the theory predicted that the surface energy is negative for the interface between adjacent superconducting and normal regions, which is in contradiction with a latter predictions [2].

## 1.5 GINZBURG-LANDAU (GL) THEORY

From 1935 until ***the isotope effect*** was discovered in 1950,some little critical theoretical work was accomplished. The isotope effect means that two different isotopes of the same element posses different ***critical temperature*** $T_C$. It is found that there is a relation, for some simple metals, between the ***critical temperature*** and the atomic mass of the isotopes [4]. In 1950, ***H.fröhlich*** developed a theory based on the interaction of electrons with vibrating atoms in the crystal lattice [20]. This explained the isotope effect but failed to predict other properties of superconducting state [4].

A quantum theory should be taken into account because of the two following reasons: first one is that the superconducting state is more ordered than the normal one. The second one is that the transition from one state to the other (without magnetic field) is a second order phase transition [2]. This implies the existence of an order parameter, ψ, for a superconducting state, which is found to be nonzero at $T<T_C$ and vanishes at $T \geq T_C$ [1]. In 1950, The first phenomenological quantum theory of superconductivity, which is a local theory, was the ***Ginzburg-Landau (GL)*** theory. The ***GL theory*** is based on the theory of second –order phase transitions developed by ***Landau*** [5, 11]. ***Landau*** Proposed a general theory of second order phase transition based on three fundamental assumptions:

1- The order parameter ψ is a function of temperature and exist in the range $0 \leq T \leq T_C$.

2- The free energy may be expanded in even power of this order parameter.

3- The coefficients of the expansion are regular functions of temperature T.

According to this theory, the superconducting state is presumed to be different from the normal state in the presence of the internal order (as yet undefined) that is characterized by an order parameter. In the framework of this theory, it assigned to the entire number of superconducting electrons as wave function depending on a single spatial coordinate [2]. This theory has introduced two equations, by which one can calculate both the distribution of the fields and the variation of the number of superconducting electrons. In order to do this, ***Ginzburg and Landau*** introduced two parameters [5, 21].

The first parameter relates to the variation of the magnetic field and the second one relates to the variation of the order parameter (wave function) or the variation of the density of ***superelectrons*** [19].

Since the theory is a phenomenological one, significant parameters are expressed in terms of experimentally measured quantities. The first one is related to the experimental ***penetration depth,*** $\lambda$, in the limit of very weak external field. The second one is related to what is so called ***Pippard coherence length*** $\xi_o$ . where a ***coherence length*** is postulated earlier by ***Pippard*** in 1951 to explain the results of high frequency measurements in superconductors [12, 22]. Because of the disagreement between the value of the ***penetration depth*** in ***London*** formula and the corresponding experimental value ***Pippard*** proposed that there is a pair correlation between electrons extending to a certain distance known as correlation length which is of order $\xi_o$. From this point of view, the current is determined not only directly at the point of observation but also in the entire region around this point with a radius of order $\xi_o$. Therefor, the relation between the current and the field becomes nonlocal one [3].

The GL theory introduced this parameter $\xi_o$ as a function of temperature T, $\xi(T)$, which is called ***the Ginzburg – Landau coherence length***. Also they introduced the so called ***Ginzburg – Landau parameter***, $\kappa$, which is defined as the ratio between the London penetration depth $\lambda(T)$ and the ***Ginzburg – Landau coherence length*** $\xi(T)$. This parameter, $\kappa$, as we will see latter is related to the classification of the superconductors. In the vicinity of $T_C$, this parameter tends to be a constant value. Since the sign of the surface energy depends on the ratio of ***the London penetration depth*** and ***the Ginzburg – Landau coherence length***, then it is natural to classify superconductors according to the value of the ratio $\lambda/\xi$.

## *1.5.1 Type - I and Type - II Superconductors*

It is found that when the GL parameter $\kappa < \frac{1}{\sqrt{2}}$ the surface energy between normal and superconducting regions is positive, while for $\kappa > \frac{1}{\sqrt{2}}$ this surface energy becomes negative. For $\kappa = \frac{1}{\sqrt{2}}$ this energy will vanish [2]. Latter, this leads to the classification of superconductors into ***type I*** and ***type II*** according to whether the surface energy is positive or negative, respectively. The importance of this classification lies not only in the distinct classification but also because ***type II*** superconductor may have an extremely large critical field, allowing the construction of superconducting magnet [14]. GL theory has successfully surmounted the difficulties of ***London electromagnetic theory***, for example, it explained the origin of the positive surface energy [2].

In the limit $\lambda >> \xi$ , we return to London el ectrodynamics. Thus this limit is called the London limit. In the opposite limiting case, $\lambda << \xi$ , such superconductors are called ***Pippard superconductors***. ***Pippard's*** nonlocal electrodynamics equation not only fitted the experimental data but also anticipated the form of electrodynamics founded several years later from the microscopic theory [3]. ***Abrikosov*** and ***Zavorisky*** first predicted the existence of ***type II*** superconductors in 1952 beside the existence of ***type I***, which was known earlier. **A. Abrikosov** investigated this type in his article [12,23]. He refined ***the GL theory*** to superconducting alloys and referred that the superconductors don't necessarily have positive surface energy (***type I***) but the majority of supercoducting alloys and chemical compounds have a negative surface energy (***type II***).

## *1.5.2 The Magnetic Properties of Type-II Superconductors*

For ***type II*** – superconductors, there is no ***Messiner effect*** above the lower magnetic field $H_{C1}$.The magnetic field penetrates the material sample in untraditional way. Magnetic flux can penetrate a ***type–II*** superconductor in the form of tiny tubes called Abrikosov vortices, each one is carrying a quantum magnetic flux [1]. The quantization of magnetic flux is a consequence of the variation of the phase of the superconducting order parameter by $2\pi n$ upon making a complete turn around the closed loop. The vortices reside at the corners of an equilateral triangles. This is the magnetic structure that would be set up in an ideal homogenous ***type II*** superconductor for fields between the ***lower critical magnetic field*** $H_{C1}$ and the ***higher critical magnetic field*** $H_{C2}$, at the same time the superconductor is stable in this region. This region where $H_{c1} < H_o < H_{c2}$ is defined as the mixed state [3,24], while De Gennes called it ***Shubnikov state*** [25]. It is found that when the applied magnetic field is perpendicular to the surface of the superconductor, the upper critical field is truly $H_{C2}$. For the case in which the magnetic field is parallel to the surface, one gets another critical magnetic field for nucleation of surface superconductivity. This critical magnetic field is approximately twice the critical field for bulk superconductivity. We shall refer to this new critical field as the third critical field $H_{C3}$, $H_{C3}=1.69H_{C2}$ [1]. The mixed state is demonstrated by Eβmann and Träuble [26].

Every vortex has a normal core, in such that its axis is parallel to the external magnetic field. This core has a radius $\xi$ ***(coherence length)***, and inside it the order parameter is zero, while the magnetic field is maximum. Also this core is surrounded by a superconducting region, of larger radius $\lambda$, within which the magnetic flux, and shielding or screening current flowing together around the core. As a result of this, one gets a maintained field within the core. On the other side, the current density of these shielding currents decays with distance from the core exponentially. It is important to refer that the vortices arrange themselves at the distance ~ $\lambda$ [1].

Once the applied magnetic field, $H_O$, is equal to $H_{C1}$, the vortices are near the surface and isolated. Also the vortex lattice persists at much higher fields. As the applied field increases more vortices enter, and their mutual repulsion and tendency to diffuse causes them to migrate inward. Eventually they become sufficiently dense and close enough to experience each other mutual repulsive forces, so they begin to arrange themselves into more or less regular pattern (the lattice period steadily decreases) [2]. At $H_O=H_{C2}$ the distance between the vortices becomes very small and in the order of ***coherence length*** $\xi$. Thus the normal cores of the vortices touch together and hence the material converts to normal.

The vortex during the penetration in a SC is delayed significantly due to the presence of a surface barrier. The surface barrier which prevents the vortices from entering and leaving the sample was considered first by ***Bean- Livingston (BL)*** [27]. According to ***BL***, the barriers arise from the competition between two forces:

1- Attraction between the flux line and its mirror image, pushing the vortex line outside the sample.

2- Interaction between the line and surface shielding current pushing it inside the sample.

An extended classification of surface and edge barriers was given by Brandt [28]. Also the effect of a surface (edge, geometrical) barrier on magnetic characteristic of type-II superconductors has been an issue of considerable interest recently [29-34]. A closely related problem is the onset of a magnetic flux (vortices) in superconducting sample [35]. The influence of an ideal (defect-free) surface on the conditions for the vortex entry was studied in detail in a number of works [35-37].

The problem in a classical superconductor is to pin the vortices which may be obtained by increasing the number of defects by doping techniques or by using anisotropic material or by ion bombardment. As the result of this the critical current should be increased. These vortices and their interactions with inhomogeneities and defects of the material (pinning) determine the ability of superconductor to carry a current without a resistance [38].

# *1.6 THE MICROSCOPIC (BCS) THEORY*

***J.Bardeen, L.N.Cooper,*** and ***J.R.Schrieffer***, in 1957, have developed a successfully microscopic or quantum theory of superconductivity (***BCS theory***) [39]. According to BCS theory, all electrons in superconductor, at zero temperature, are paired and called Cooper pairs. For the case of finite temperature ($T \neq 0K$) we have both Cooper pairs and single electrons.

***Cooper pair*** consists of two binding electrons with equal and opposite momenta. Also their spins are equal but are opposite in the direction. In order to let the electrons attract with each other, the energies of both electrons, must be less than $k_B\Theta_D$ ($k_B$ is Boltzman constant, and $\Theta_D$ is Debye temperature). This energy must be larger than the coulomb repulsion. The mean separation length, at which this pair correlation exists, is called cooper pair coherence length $\xi_{co}$. These cooper pairs exist in one quantum state. Thus they have one wave function, in such that the square of the amplitude gives cooper-pair density $n_s/2$, where $n_s$ is the number of superelectrons. One wave function for the electrons of cooper pair means that they have a coherence phase. The large number of the particles in one state (Condensed State), means that there will be a difficult for any one of them to leave this state. This process is called Bose condensation. It should be mentioned here that at $T<T_c$ there exists condense of ***cooper pairs*** which means that the dissipation –free electric current is carried by these cooper pairs. Since the ***cooper pairs*** have integral spins, then they considered as a boson (obeys Bose-Einstein statistics). This implies that they can occupy one state with the same quantum number. On the other hand, in the excited situation the ***cooper pairs*** break up into single electrons. We must remember that the electrons that are produced are fermions (have half-integral spins) which obey Fermi-Dirac statistic [4].

Due to the exchange of phonons between the interacting electrons of cooper pairs, the state of the unpaired electrons will be changed. In addition, a very narrow energy range around the Fermi energy being forbidden for the electrons. Thus an "***energy gap (2Δ)***" is formed which means that we can only break up a cooper pair with a minimum energy equal to $2\Delta$. At zero temperature this energy is given by $2\Delta=3.52k_BT_C$. Breaking up the pairs leads to the excitation situation for which one can observe that the energy gap decreases with temperature and vanishes at $T_C$. Furthermore, for conventional superconductors there is a threshold frequency~$10^{11}$ Hz and above this frequency the superconductors behave just like normal metals [19]. The existence of energy gap has been observed experimentally by absorption electromagnetic radiation [40], absorption of ultrasound [41], and by what so called tunnel effect [42, 43]. In the first few years after the discovery of ***BCS theory*** the existence of an energy gap is considered as a fundamental characteristic of the superconducting state. There were many experiments before the development of the ***BCS theory*** which are associated with the studying of the behavior of the ***specific heat***, the ***isotope effect***, ***second – order phase transition***, ***Meissner effect***, ***flux qunatization***, and other thermodynamic and electromagnetic properties of superconductors. BCS theory calculated successfully all that. Also ***BCS theory*** is the first one, which has been used for investigating some other experiments, like the measurement of the ***tunnel effect*** and ***Josephson effect*** [4].

In 1958, **Gorkov** developed a method to find a relationship, which interprets all phenomenological parameter of the ***GL theory*** in view of the microscopic sight. Using Green's function he concluded that the ***GL theory***, in fact, is the limiting case of the microscopic theory [3,44]. It should be remembered that the (GL) theory is valid only in the vicinity of $T_C$. But **Gorkov**, in 1959 showed that this condition may be extended to temperature far and below $T_C$. It will be nice to refer that all postulations ***of*** **Gorokov**, ***Ginzburg***, ***Landau***, and **Abrikosov** are called GLAG theory [2].

# 1.7 HIGH CRITICAL TEMPERATURE SUPERCONDUCTORS

In September 1986, ***Georg Bednorz*** and ***Alex Müler*** (IBM-Zürich) published a paper entitled "possible high $T_C$ superconductivity in the Ba-La-Cu-O system" [12,45]. This is considered as the onset for the so called higher transition temperature superconductor (***HTSC***). It was found that the system "Ba-La-Cu-O"(LBCO)[a mixed oxide of lanthanum, barium, and copper] becomes a superconductor at ~35K. Furthermore ***HTSC's*** systems have been discovered such as La-Sr-Cu-O (LSCO) [a mixed oxides of lanthanum, strontium, and copper] and Y-Ba-Cu-O (YBCO) [a mixed oxides of yttrium, barium, and copper]. These systems were discovered independently, in Beijing, by Z.X.Zaho and his workers [46]. The $T_C$ of the system Y-Ba-Cu-O was 92 K [47]. For this system the Y-element can be replaced by many other rare elements, e.g., La, Nd, Eu, Gd, Ho, Er, and Lu, which have a similar high $T_C$ [1]. As a continuation of earlier researches of ***HTSC***, in 1988 , a new superconductors have been prepared by using the following systems Bi-Sr-Ca-Cu-O (BSCCO) [mixed oxides of bismuth, strontium, calcium, and copper] with $T_C$ up to 110K [48] and Tl-Ba-Ca-Cu-O (TBCCO) [mixed oxides of thallium, barium, calcium, and copper] with $T_C$ values of over 120K [49].

Excluding to some materials like $Ba_{1-X}K_XBiO_3$, where x indicates a partial oxygen content, most ***high-$T_C$ superconducting*** oxides are cuprate compounds (have copper oxide planes). This is a more surprising and exciting for scientists, because of not only the large increment in $T_C$, but also due to that oxides may form an unsuspected new class of superconducting materials with great potential [19].

The main difference between the classic superconductors and ***HTSC*** is that the last one has extremely short coherence length. Some examples for different values of the coherence length and penetration depth are presented in table (1) [1]. High $T_C$ superconductors are highly anisotropy materials due to it's layered crystal structure. According to this fact there are two critical magnetic fields, which are associated with the field direction, in such that, one of them is parallel and the other perpendicular to the planes. Also London penetration depths and the coherence lengths are found to be anisotropic: $\lambda_{ab}$, $\lambda_c$, $\xi_{ab}$, $\xi_c$ (a, b, and "c" are the crystallographic principle axes direction). ***HTSC's*** are considered as inhomogeneous superconductors, i.e., the layered crystal structure of them is linked to the modulation of the order parameter [2]. At the same time ***HTSC's*** oxides have metallic properties, while most oxides are insulating materials.

There is no definite theory yet to explain their higher critical temperature. Since ***HTSC's*** are extremely ***type II*** then the electrodynamics for them can be described by a local London equation. Since there is no an axial symmetry for this kind of superconductor, its effective mass of it must be replaced by what is referred as the effective mass tensor. Due to the anisotropic London equation of ***HTSC's***, the isolated vortex has circular cross section in the c-axis while has an elliptical cross section in the ab-plane (the difference between a and b axes is very small). Also high $T_C$ superconductors can be described by the generalized ***GL*** equations by taking into account the anisotropic effective mass. These equations are valid only for the compounds, which have a small anisotropy. For high anisotropy, ***the GL approach*** has been replaced by more general model, which is known as Lawernce –Doniach model [12]. This model has been used successfully to account for many properties of highly anisotropy ***HTSC's*** for which the coherence length along c-axis must be very small with respect to the distance between the Cuo layers [12]. The very short coherence lengths may be lead to unusual behavior for example:

1- ***HTSC's*** can obtained when the insulator is slightly doped. For these ***HTSC's*** the, superconductivity disappears as the doping increase.

2- In ***HTSC's***, the irreversibility line in the (H,T) phase diagram will appear.

3- It is known, in the mixed state, that the resistive transition of a conventional superconductor shifts downwards with increasing magnetic field. But in the case of ***HTSC's***, it is found that the resistive transition broadens as the magnetic field increases [19].

It is clear that ***HTSC's*** have a lower pinning force than those associated with the classical superconductor. Since the defects, which pin vortices in ***HTSC's*** , have to be of order of few Angstrom . Contrary to classical superconductor materials atomic defects can pin the vortices. Thus the oxygen vacancies are thought to be important pinning centers.

These defects may be a point defect, a dislocation defect, grain boundary, twin boundary, praseodymium doping, columnar defect, or oxygen vacancies. All these defects can prevent the motion of vortices, and therefor the pinning force (a short rang force) will pin the vortices. These processes occur usually at the inhomogeneities regions in the material [1,12]. When a current acts on the superconductor, four forces will be formed as Lorentz force and the repulsion force which arises from the interaction between the current density of a vortex with the flux of another one. Besides these two forces there are another two forces which are called the damping force and Magnus force. Vortices can undergo thermally activation as due to their hopping between pinning centers [4]. When the transport current is small, this means that the pinning force is larger than Lorentz force, the vortices move slowly. This case is called the flux creep (the field penetrates very slowly). Flux creep is classified into two types, one of them occurs at zero temperature, i.e., $I<I_C(0,B)$,in such away that there is no dissipation of the vortices energy. The other type occurs for $0 \leq T \leq T_C$, i.e., $I<I_C(T,B)$ for which there will be an observable dissipation for the energy. The last process is called the thermal activated flux creep. The dissipation is a process through which the electrical energy, which is resulted from transport current, transforms into heat and this is due to the motion of the vortices through the superconductor. On the other hand at large transport current $I>I_C$, i.e., Lorentz force is larger than the pinning force, the motion becomes larger than before. This situation is called flux flow, while the collective motion is called flux bundle [4,19]. All these processes are very important to determine the critical current of a superconductor, where the definition of the critical current is that, it is the current at which the vortices move freely. Therefore for an ideal type II superconductor having zero critical current is associated with a finite electrical resistance [50].

called critical state models. Each critical state model is based on a particular relationship, which is assumed between the internal field and the critical current density. The critical state is discussed by different models such as: fixed pinning model, square root model, Kim model, Exponential model, linear model, quadratic model, triangular model, and generalization model [1]. For example fixed pinning model assumes the pinning force is constant. Other models assume a more complex relationship between the internal field and the current density except Bean model. In Bean model the flux profiles are simply straight lines. He assumed that the critical current to be constant. In the framework of this model, one can determine the maximum gradient of the field. Also using this model one can estimate the critical current through the measurement of the magnetization of the considered sample [51].

As a result of the motion of the vortices through superconductor an important effect is developed; that is called the fluctuation effect. Where by increasing the temperature a vibrational motion occurs on the vortices by which one can get a thermal fluctuation. It is useful to state here that this effect depends on the elastic constants (shear, bulk, and tilt). Thermal fluctuations can have important effects on the properties of supercoductors.

the vortices by which one can get a thermal fluctuation. It is useful to state here that this effect depends on the elastic constants (shear, bulk, and tilt). Thermal fluctuations can have important effects on the properties of supercoductors. In classic superconductor this effect is weak, while it is very important in ***HTSC*** [19].

# *1.8 THE SHAPE OF THE VORTICES*

It is known that the high temperature superconductors are highly anisotropic and the electrodynamic behaviors of these materials are strongly affected by the anisotropy of its layered structure. The magnetic properties are determined by the properties of vortices, which can be regarded as stacks of two-dimension (2D) pancake vortices [52-57]. In the absence of defects (i.e., when there are no pinning centers present), most of the interesting physical properties can be understood theoretically in terms of ***the anisotropic Ginzburg-Landau theory*** [58-61]. In this ***Ginzburg-Landau picture***, magnetic fields penetrate into superconductor in the form of continuous vortices. When the vortices are inclined by an angle $\theta$ relative to the c-axis of strongly anisotropic layers superconductors with the dimensionless effective mass, along the c-axis $m_c << m_{ab}$ (a,b and c are the principle axis direction), the ***supercurrents*** flowing around the vortex axis tend to flow not in circular paths in planes perpendicular to the vortex axis, as in isotropic superconductors, but in roughly elliptical paths that are nearly parallel to the layers [58,59]. Pancake vortices are characterized by circular ***supercurrent*** patterns confined to superconducting layers.

In the limit of extreme anisotropy, a vortex line threading through a stack of superconducting layers can be regarded as a stack of magnetically coupled (2D) pancake vortices, with one pancake vortex in each layer. In this limit, for which the Josephson coupling between layers is zero and the ***penetration depth*** along the c-axis $\lambda_c$ is infinite, it is possible to calculate the magnetic field generated throughout space by a single isolated vortex. For circular pancake vortices, an analytical solution can be obtained [52-55,57,62]. It is important to study the properties of pancake vortices, which are characterized by elliptic ***supercurrent*** patterns confined to the superconducting layers. The purpose of this thesis is to study the electromagnetic properties of elliptic closed vortex line in bounded type-II superconductors. This study can form the basis of calculations of the physical properties of the vortices in terms of 2D pancake vortices in layered superconductors.

A good general survey as well as richly detailed review of the conventional and high temperature superconductors is given by [1-5,12,19,63-66].

In this work, we limited ourselves to the case of type II supercoductors of elliptic cross section. Really, for ***high temperature superconductors***, which a rate of high anisotropy, though equation for anisotropic superconductors can not be exactly reduced to the isotropic case direct scaling transformation [58,59,67-69], valid for strong magnetic fields. Nevertheless the process of closed- loop nucleation as well as vortex- loop entry into a layered superconductor in the presence of a transport current should be very similar to that in the isotropic case.

## *1.9 THE AIM OF THE PRESENT WORK*

To study the effect of the geometry of the superconducting samples on the magnetic behavior of ***type II*** superconductors. This is done through the analysis of the results of the magnetic flux, the free energy and the Gibbs free energy of the system, the height of the potential barrier, and the critical current density for a circular cylinder and elliptic cylinder samples with circular and elliptic vortices respectively.

In chapter II, we used the ***London model*** to study the structure of the elliptical vortex inside the sample, which has been considered. In the framework of this model, ***London equation*** in terms of the elliptic cylinder coordinates is derived. This equation has been solved analytically to get the distribution of the magnetic field inside the vortex.

After that, we derived both the vortex magnetic field and the free energy of the system. Also the Gibbs free energy has been derived for both collapsing and expanding vortices. Moreover the height of the created potential barrier and the critical current for both collapsing and expanding vortices have been derived.

In chapter III, the following physical quantities: the magnetic flux, the free energy, the Gibbs free energy, the height of the potential barrier, and the critical current have been computed for different semi major axes samples with different ***Ginzburg- Landau parameters***. A discussion for the results of the above calculations has been done. Also a comparison between the present results in cylinder case and the corresponding published values is done.

The thesis is concluded by some discussion and conclusions.