CHAPTER - 2
REVIEW OF LITERATURE

Superconductivity was first discovered and so named by **Kamerleingh Onnes** in 1911. He observed that the resistance of a sample of Mercury dropped from 0.08 Ω at about 4k to less than 10^{-6} Ω over a temperature interval of 0.01 k**.**

Meissner effect is a main characteristic of a superconductor. It was first observed by **W. Meissner and R. Ochsenfeld** in 1933 when they were cooling a superconductor in a magnetic field to below the transition temperature, then at the transition temperature T_C, the lines of induction B are pushed out. By the Meissner effect, it is clear that a superconductor is a perfect diamagnet.

F. Landon and H. London in 1935 gave an equation to explain the meissner effect. The equation is called London equation & is written as-

$$B(x) = B(o) \exp(-x/\lambda_L)$$

Where B(x) is the field inside the superconductor and B(0) is the field at the plane boundary. λ_L measures the depth of the penetration of the magnetic field, and it is known as the London penetration depth. So an applied magnetic field B_a will penetrate in thin film fairly uniformly if the thickness is much less than λ_L. Thus in a thin film the meissner effect is not complete.

Bardeen, Cooper & Schrieffers in 1957 proposed a quantum theory of superconductivity. According to this theory, the electron-lattice-electron interaction leads to an energy gap of the observed magnitude. The indirect interaction proceeds when one electron interacts with the lattice and deform it, a second electron sees the deformed lattice and adjust itself to take advantage of the deformation to lower its energy. Thus the second interacts with the first electron via the lattice deformation. The

penetration depth and the coherence length emerge as natural consequences of the BCS theory. So the superconducting state is known to be an ordered state of conduction electrons. The order is in the formation of the loosely associated pairs of electrons. The electrons are ordered at transition temperature and they are disordered above the transition temperature. Thus, the central phenomenon in superconductivity, the Meissner effect, is obtained in a natural way.

J.W. Garland in 1963 observed that the superconducting state is also characterized by isotope effect. It is based on the dependence of T_C on atomic mass of the superconductors. He observed that in mercury T_C varies from 4.185 k to 4.146 k as the average atomic mass varies from 199.5 to 203.4 atomic mass units. The dependence of T_C on isotopic mass indicates lattice vibrations and hence electron-lattice interactions are deeply involved in superconductivity. There is no other reason for the superconducting transition temperature to depend on the number of neutrons in the nucleus.

Blatt & J. M. Benjamin in 1964 found that superconductivity has been observed only for those metallic substances for which the number of valence electrons (Z) lies between 2 &8.

A. B. Pippard in 1965 also found a difference between a superconductor and a perfect conductor, defined, as a conductor in which there is nothing to scatter the electrons. When the problem is detail, it turns out that a perfect conductor placed in a magnetic field, can not produce a permanent eddy current screen & the field will penetrate about 1cm in an hour.

The highest transition temperature till 1970 was 23 k for Nb_3Ge. But after a gap of 12 years **Bednoz & Muller** in 1983 discovered a high T_C cuprate layered superconductor $LaBaCuO_2$. It has T_C equal to 30 k. After that series of high T_C layered superconductors

were discovered and the highest T_C reached till date is 160 k under applied pressure for $HgBaCaCuO_2$. The discovery of cuprate superconductors rekindled an old dream that one-day room temperature superconductivity might be achieved. But with this discovery, most of workers believes that the conventional BCS theory is not adequate to explain the superconductivity with such high transition temperatures in these systems.

R.V. Kasowski et al. in 1983 observed that all the Cooper-oxide based superconductors are based on the structures with square planner copper oxide layers**.** These CuO_2 layers are responsible for conduction and increase in their number per unit cell increase transition temperature T_C.

The subsequent discovery of the $YBa_2Cu_3O_7$ (90 k superconductor) by **M. K. Wu et. al.** in 1987, has emphasized the importance of antiferromagnetic interactions and their possible relevance to superconductivity in the cuprate perovskites. With the expectation that antiferromagnetic correlations should be common to all layered cuprate perovskites, a thorough study of antiferromagnetic correlations in layered copper oxide is vital to understand the mechanism responsible for the abnormal properties of HTSC layered compounds.

J. M. Tranquada et al. in 1988, has been shown that antiferromagnetism (AFM) in these compounds is due to weak interlayer coupling ($J_\perp$), which is a display of the large amount of orthorhombic distortion present in the HTSC layered compounds. It is believed that layered antiferromagnets like La_2CuO_4 (2-1-4) and $YBa_2Cu_3O_{6+x}$ (1-2-3) have strongly anisotropic antiferromagnetic correlations and fairly large Neel temperatures. It has been experimentally established that these properties are the manifestations of a strong intraplanar antiferromagnetic exchange coupling constant ($J_\parallel$) and a weak interlayer coupling constant ($J_\perp$) between the copper oxide (CuO_2) planes.

J. M. Tranquada et al. in1988 explained the dependence of the Neel temperature (T_N) on the doping concentration of oxygen in $YBa_2Cu_3O_{6+x}$ (1-2-3) compounds by Neutron diffraction experiments. The Neel temperature decreases with increasing oxygen concentration in $YBa_2Cu_3O_{6+x}$ and at a critical value x = 0.4, T_N is found to be reduced to zero. The system undergoes an insulating antiferromagnetic tetragonal-to-orthorhombic superconducting phase transition. In these oxide materials the superconducting phase occurs near a metal–insulator transition at which the system undergoes an antiferromagnetic as well as structural instability. This fact has generated many ideas and proposals for a new mechanism but without a significant breakthrough.

J. E. Hirsch et al. in 1989 analyzed that these layered materials possess anisotropy in their structure and due to this various physical properties in the normal and superconducting phase also show anisotropic behaviour. It is pointed out that at superconducting transition the anisotropy in the resistivity matches well with the square of the anisotropy in penetration depth. However, below transition temperature the system becomes superconducting in all the three directions. To analyze the role of third direction it is important to understand how conduction of charge carriers in this direction is taking place.

J. W. Lynn in 1990 reported that the anisotropy in antiferromagnetic correlation coupling in certain materials plays an important role in the magnetic properties. For example, high temperature superconductors are antiferromagnetic in normal state and it has already been experimentally established that they have large difference in the antiferromagnetic coupling constant within CuO_2 planes and between the CuO_2 planes in the c-direction. They have anomalous magnetic and electronic properties due to this anisotropy.

A. Singh et al. in 1991 have pursued the role of the interlayer coupling in magnetic dynamics of copper-based antiferromagnets even further. They have argued that the excitation of spin waves in anisotropic antiferromagnets such as 1-2-3 results in a characteristic dependence of sublattice magnetization on temperature. Further, due to these excitations there is a crossover from 3D to quasi-2D behaviour with temperature dependence of sublattice magnetization varying from - T^2 (3D case) to ~ T In T (quasi-2D case). According to them, the Neel temperature in copper-based antiferromagnets falls logarithmically with decreasing interlayer coupling.

R. P. Singh et al. in 1992 have obtained an analytical expression for the Neel temperature, $T_N = J_{\parallel} / \left[0.1616 \ln\left(J_{\parallel} / J_{\perp}\right) + 0.5055\right] / K_B$, derived from the three – dimensional anisotropic Heisenberg model in the random – phase approximation. This expression shows that Neel temperature $T_N \to 0$ as $J_{\perp} \to 0$. They have also compared their theoretical results with the doping – dependent Neel temperature of $YBa_2Cu_3O_{6+x}$ compounds. Good agreement between theory and experimental results is achieved providing that the ratio of the interplanar to intrapanar coupling strength depend linearly on the doping concentration x. Further the intraplanar coupling strength is treated as a constant independent of x in the numerical calculations.

Ajay et al. in 1995 also studied the role of interlayer coupling $(J_{\perp})$ on the Neel temperature of (1-2-3) compounds by taking the three-dimensional anisotropic Heisenberg antiferromagnetic model. They considered the two-sublattice model of the antiferromagnet and estimated the Neel temperature (T_N) for $YBa_2Cu_3O_{6+x}$ (1-2-3) compounds as a function of doping concentrations (x). The intraplanar coupling strength $(J_{\parallel})$ is treated as a constant throughout the numerical calculations. The theoretical results have good agreement with that of the random phase approximation (RPA) and existing experimental results.

A. Pratap et al. in 1996 have analyzed the magnetic dynamics of quasi-2D high-T_C antiferromagnets within nonlinear spin-wave approximation. The Green function method within the random phase approximation (RPA) is used to obtain the expressions for various magnetic properties such as staggered magnetization, specific heat, parallel and perpendicular susceptibilities. These properties have been analyzed by introducing an effective ratio ($r^2 = J_\perp / J_\parallel$) of intraplanar to interplanar antiferromagnetic (AFM) coupling strengths. The magnetic properties are found to be dependent on the renormalization factor ($1 + a$), r^2, and temperature T, and it is shown that the magnon-magnon interaction plays a significant role in modifying the crossover temperature and other magnetic properties. Its effect in 2D is more pronounced than in 3D antiferromagnets.

V. J. Emery et al. in 1997 reported that high T_C cuprates can be viewed as doped antiferromagnetic insulators with the charge carriers transferred into perfect CuO_2 planes from the charge reservoir layers. In general, there is a tendency for AF insulators to expel doped holes and to show a phase separation into regions with and without the doped holes. When the ions are not mobile and the coulomb interaction between doped holes is effective, an intriguing microscopic state with holes gathered within an array of quasi-1D stripes may be realized.

T. Timusk and B. Statt in 1999 experimentally analyzed the rise and fall of T_C as a function of doping leads to the classification of the corresponding regions of the chemical phase diagram as "underdoped" and "overdoped" regimes, respectively. At a first glance, the physical properties of these two regimes seem to be not so different for the superconducting state, but they are dramatically different for the normal state. In the underdoped regime for temperatures far above T_C, even up to room temperature, a peculiar redistribution of electronic states in the energy spectrum is observed in the vicinity of the Fermi energy resembling the features of a superconducting energy gap. The critical temperature associated with this "*pseudogap*" energy decreases

monotonically on doping, in stark contrast to the monotonic increase of T_C in this doping regime.

G. Aeppli et al. in 1999 reported that the neighborhood of the pseudogap and superconductor phases to the AF phase in the temperature-doping phase diagram points to a spin-related superconductivity mechanism. Starting out from static AF order for the undoped case, it is plausible that on increasing the doping strong AF correlations will persist in the underdoped pseudogap regime. The Bragg peaks which result from the doubling of the real space unit cell due to antiferromagnetism survive in broadened versions, at least in the form of spin fluctuation patterns which can be probed by inelastic neutron scattering (INS). Surprisingly, in the underdoped regime for $T < T^*$ the single peaks in reciprocal space found in the insulator split into four, each displaced in orthogonal directions by a small amount.

Z. A. Xu, et al. in 2000 observed an another amazing experimental finding was the discovery of vortex-like excitations in the pseudogap phase of underdoped HTS well above T_C, which indicate the presence of strong SC fluctuations even in this normal state. This point to the idea of "preformed (Cooper) pairs" which exist already above T_C as noncoherent fluctuations and achieve coherent behavior only at lower temperature after condensation into the SC state.

Krasnov et al. in 2001 analyzed the gap structure in the presence of magnetic fields by tunneling spectroscopy for $Bi_2Sr_2CaCu_2O_{8+\delta}$. They reported that the pseudogap is independent of temperature and magnetic fields for an optimally doped specimen and concluded that the superconducting gap and the pseudogap coexist in the superconducting state. It is still unclear what relationship pseudogap is having with superconductivity, whether they are different manifestation of same correlations or they are different phenomenon altogether.

Govind et al. in 2001 studied the magnetic properties of bilayer cuprate antiferromagnets (i.e. undoped $YBa_2Cu_3O_{6+x}$). He reported that the spin wave dispersion curve for a bilayer antiferromagnetic system is found to consist of one acoustic and one optic branch. The "optical magnon gap" has been attributed solely to the intra-bilayer exchange coupling ($J_\perp$) as its magnitude does not change significantly with the inter-bilayer exchange coupling (J_z). However inter-bilayer exchange coupling J_z is essential to obtain the acoustic mode contribution to the magnetization. The Néel temperature (T_N) of the bilayer antiferromagnetic system increases with the J_z and a small change in J_z gives rise to a large change in the Neel temperature of the system. The magnetic specific heat of the system follows a T^2 behaviour but in the presence of inter-bilayer exchange coupling J_z it varies faster than T^2.

J. Tallon et al. in 2002 reported the observation of microscopically coexisting ferromagnetism and superconductivity in a hybrid ruthenocuprate $RuSr_2GdCu_2O_8$, with T_C = 40 k. By means of various substituents it is established that the superconductivity originates in the CuO_2 planes and the ferromagnetism in the RuO_2 planes, as expected. Muon spin relaxation measurements show that the ferromagnetism, with Curie temperature T_M = 132 k, is microscopically uniform and originates from the entire sample bulk. This is probably the first confirmed example of uniform microscopic coexistence of superconductivity and atomic ferromagnetism. The material is determined from thermopower measurements to be an underdoped cuprate with a projected T_{Cmax} = 90- 100 k, typical of a two-layer cuprate. The oxygen isotope effect exponent of α_{Tc} = 1.7 is the largest observed in the high- T_C cuprates. These materials are expected to provide a rich source of new physics and applications.

Amit Keren and Amit Kanigel in 2003 discussed many compounds based on CuO_2 planes (cuprates) superconduct below a critical temperature T_C. Some of them show a second phase where a spontaneous static magnetic field appears below a critical temperature T_g, which is lower than T_C. By comparing T_C and T_g in numerous

superconducting families, each with its own maximum T_C, they found that the same energy scale determines both critical temperatures. This clearly indicates that the origin of superconductivity in the cuprates is magnetic.

A. Shengelaya et al. in 2004 performed zero-field muon spin rotation (ZF-μSR) and dc magnetization experiments in the ruthenate-cuprate $Eu_{1.4}Ce_{0.6}RuSr_2Cu_2O_{10}$. They found that this compound becomes weakly ferromagnetic at T_m = 77.6 k and superconducting below T_C = 40 k. ZF-μSR experiments indicate that the magnetic order accounts for most of the sample volume and magnetism is not significantly affected in the superconducting state. This investigation provides evidence for the coexistence of magnetism and superconductivity in $Eu_{1.4}Ce_{0.6}RuSr_2Cu_2O_{10}$.

B. Lake et al. in 2004 discussed neutron scattering measurements on the cuprate, high transition temperature superconductor $La_{2-x}Sr_xCuO_4$ (LSCO) in an applied magnetic field. LSCO is a type-II superconductor and magnetic flux can penetrate the material via the formation of vorticies. Phase coherent superconductivity characterized by zero resistance is suppressed to the lower field-dependent irreversibility temperature ($T_{irr}(H)$) and occurs when the vortices freeze into a lattice. Because superconductivity is destroyed within the vortex cores, an investigation of the vortex state provides information about the ground state that would have appeared had superconductivity not intervened. Their measurements reveal that both optimally doped LSCO (x = 0.16, T_C = 38.5 k) and underdoped LSCO (x = 0.10, T_C = 29 k) have an enhanced antiferromagnetic response in a field. Measurements of the optimally doped system for H = 7.5 T show that inelastic sub-gap spin fluctuations first disappear with the loss of finite resistivity at T_{irr}, but then reappear at a lower temperature with increased lifetime and correlation length compared to the normal state. In the underdoped system elastic antiferromagnetism develops below T_C in zero field, and is significantly enhanced by application of a magnetic field; phase coherent superconductivity is then established within the antiferromagnetic phase at T_{irr}.

Y. Koike et al. in 2005 investigated the inhomogeneity of the impurity- and field-induced magnetic order and superconductivity in the hole-doped $La_{2-x}Sr_xCuO_4$ (LSCO), $La_{2-x}Ba_xCuO_4$ (LBCO) and the electron-doped $Pr_{1-x}LaCe_xCuO_4$ (PLCCO). For the hole-doped cuprates, it has been found from the muon-spin-relaxation measurements that both Zn and Ni impurities tend to develop a magnetic order and to destroy the superconductivity around themselves not only around p (the hole concentration per Cu) = 1/8 but also at $x = 0.15$ and 0.18 in LSCO, though the development of the magnetic order by Zn is more marked than by Ni. Moreover, it has been found from the thermal conductivity measurements that the development of the magnetic order by the application of magnetic field is marked not just at $p = 1/8$ but in the neighborhood of $p = 1/8$ in LSCO and LBCO. The impurity- and field-induced magnetic order in the hole-doped cuprates can be interpreted as being due to pinning of the dynamical stripes of holes and spins by impurities and vortex cores in the CuO_2 plane, respectively. For the electron-doped PLCCO with $x = 0.14$, on the contrary, no impurity-induced magnetic order has been observed.

V. P. S. Awana et al. in 2005 synthesized $RuSr_2(LnCe_2)Cu_2O_{12.25}$ (Ru-1232) compounds with Ln = Y and Dy by high pressure & high temperature (6GPa, 1200°C) solid state synthesis route crystallize in space group *P*4/*mmm* in near single phase form with small quantities of $SrRuO_3$ and $RuSr_2(RE_{1.5}Ce_{0.5})Cu_2O_{10}$ (Ru-1222). Both samples exhibit magnetic transitions ($T_{mag.}$) at 90 k with significant branching of zero-field-cooled (ZFC) and field-cooled (FC) magnetization and a sharp cusp in ZFC at 70 k, followed by superconducting transitions at 30 k. Both compounds show typical ferromagnetic hysteresis loops in magnetic moment (M) versus field (H) magnetization right up to $T_{mag.}$ i.e., < 90 k. These are the first successfully synthesized Ru-1232 compounds in near single phase with lanthanides including Y and Dy. These results are compared with widely reported Gd/Ru-1222 and Ru-1212 ($RuSr_2GdCu_2O_8$) compounds. In particular, it seems that the Ru moments magnetic ordering temperature

($T_{mag.}$) scales in the *c*-direction distance between magnetic RuO_6 octahedras in Ru-1212/1222 or 1232 systems.

S. Shimizu et al. in 2007 reported on the onset of antiferromagnetism in F-substituted four-layered high- T_C compounds $Ba_2Ca_3Cu_4O_8(O_{1-y}F_y)_2$ ($2y$=1.2,1.4,1.6 and 2.0) which are composed of two types of CuO_2 planes in a unit cell; three inner planes (IPs) and two outer planes (OPs). The Cu-NMR study has revealed that the hole density at the OPs are slightly larger than that at the IPs, and a total carrier density decreases as F content increases. The observation of zero-field Cu-NMR spectra over a broad frequency range has demonstrated that antiferromagnetically ordered phases emerges at low temperatures for all compounds. This result is similar to the case for the five-layered cuprates $HgBa_2Ca_4Cu_5O_y$ where the optimally doped OP undergoes a superconducting (SC) transition, whereas the three underdoped IPs do an antiferromagnetic (AFM) transition. This result gives evidence for a coexistence of antiferromagnetism and superconductivity in four-layered high- T_C cuprates.

Vignolle et al. in 2007 used inelastic neutron scattering to demonstrate that collective spin excitations in optimally doped $La_{2-x}Sr_xCuO_4$ are more structured than previously thought. This indicate that collective spin excitations can explain features of quasiparticle spectroscopies and are therefore likely to be the strongest coupled excitations.

Niestemski et al. in 2007 have found a Bosonic excitation mode in resolution scanning tunneling microscopy measurements of the electron – doped high T_C superconductor $Pr_{0.88}LaCe_{0.12}CuO_4$ (PLCCO). This indicates an electronic origin of the mode consistent with spin excitations rather than phonons.

Y. Kohsaka et al. in 2008 reported that the antiferromagnetic ground state of copper oxide mott insulators is achieved by localizing an electron at each copper atom in real

space (*r*-space). Removing a small fraction of these electrons (hole doping) transforms this system into a superconducting fluid of delocalized copper pairs in momentum space (*k*-space). During this transformation, two distinctive classes of electronic excitations appear. At high energies, the mysterious 'pseudogap' excitations are found, whereas, at lower energies, for Bogoliubov quasi-particles the excitations resulting from the breaking of cooper pairs should exist. To explore this transformation, and to identify the two excitation types, they have imaged the electronic structure of $Bi_2Sr_2CaCu_2O_{8+\delta}$ in *r*-space and *k*-space simultaneously. They also fund that although the low-energy excitations are indeed Bogoliubov quasi-particles, they occupy only a restricted region of *k*-space that shrinks rapidly with diminishing hole density. Concomitantly, spectral weight is transferred to higher energy *r*-space states that lack the characteristics of excitations from delocalized cooper pairs. Instead, these states break translational and rotational symmetries locally at the atomic scale in an energy–independent way. They demonstrate that these unusual *r*-space excitations are, in fact, the pseudogap states. Thus, as the Mott insulating state is approached by decreasing the hole density, the delocalized cooper pairs vanish from *k*-space, to be replaced by locally translational and rotational symmetry–breaking pseudogap states in *r*-space.

Yoichi Kamihara et al. in 2008 found a new class of high T_C superconductors LaFeAs(O, F) with the remarkable T_C of 26 k. Similar to high- T_C cuprates, the superconductivity in iron arsenide compounds is related to a layered structure. The electrical conductivity and magnetization measurements demonstrate that the F^- ion-doped layered LaOFeAs is a bulk superconductor. T_C changes with F^- content, exhibiting a maximum T_C of 26 k at a F^- content of ~ 11 atom %. Further, the F^- *T* curve in the normal conducting state shows a minimum in the underdoped region. Although further research is needed to examine origins of the T_{anom}, T_{min}, and the high T_C, these results demonstrate that the layered oxypnictide, *Ln*OM*Pn* is a promising new platform to realize high T_C superconductors.

Hiroki Takahashi et al. in 2008 reported that In the copper-based high-temperature superconductors, as well as in LaOFeAs, an increase in T_C is often observed as a result of carrier doping in the two-dimensional electronic structure through ion substitution in the surrounding insulating layers, suggesting that the application of external pressure should further increase T_C by enhancing charge transfer between the insulating and conducting layers. The effects of pressure on these iron oxypnictide superconductors may be more prominent than those in the copper-based systems, because the As ion has a greater electronic polarizability, owing to the covalency of the Fe–As chemical bond, and, thus, is more compressible than the divalent O^{2-} ion. Here they report that increasing the pressure causes a steep increase in the onset T_C of F-doped LaOFeAs, to a maximum of 43 k at 4 GPa. With the exception of the copper-based high-Tc superconductors, this is the highest T_C reported to date. This result, together with the great freedom available in selecting the constituents of isocrystalline materials with the general formula LnOTMPn (Ln, Y or rare-earth metal; TM, transition metal; Pn, group-V, 'pnicogen', element), indicates that the layered iron oxypnictides are promising as a new material platform for further exploration of high-temperature superconductivity.

T. Yildirim in 2008 has shown that this stripe structure results from an inherent frustration produced by a strong next-nearest-neighbor antiferromagnetic exchange between iron spins on the square planar lattice. The observed structure is stable provided the nearest-neighbor exchange, J_1, along the square edges, and next-nearest-neighbor exchange, J_2, along the square diagonals, satisfy, $J_2 > J_1/2$. He postulates that the structural transition is a means of relieving this frustration, which implies the existence of strong short-range spin correlations above the antiferromagnetic transition temperature.

R. J. McQueeney et al. in 2008 analyzed inelastic neutron scattering measurements of the magnetic excitations in $CaFe_2As_2$ and indicate that the spin wave velocity in the Fe

layers is exceptionally large and similar in magnitude to the cuprates. The spin wave velocity perpendicular to the layers is at least half as large that in the layer. However, the out-of-plane velocities are smaller but still substantial, reduced from the inplane values by a factor of 2, so that the magnetism is more appropriately categorized as anisotropic three-dimensional, in contrast to the two-dimensional cuprates. They estimated exchange constants, for couple antiferromagnetic nearest neighbors J_{1a} = 41meV, couple ferromagnetic nearest neighbors J_{1b} = 10 meV, couples next-nearest neighbors within the plane J_2 = 21 meV, and out of plane coupling J_z = 3 meV. Exchange constants derived from band structure calculations predict spin wave velocities that are consistent with the experimental data.

Jun Zhao et al. in 2008 studied inelastic neutron scattering of magnetic excitations in antiferromagnetically ordered $SrFe_2As_2$ (T_N = 200– 220 k), the parent compound of the FeAs-based superconductors. They reported that at low temperatures (T = 7 k), the magnetic spectrum $S(Q, \hbar\omega)$ consists of a Bragg peak at the elastic position ($\hbar\omega$ = 0meV), a spin gap ($\Delta \leq$ 6.5meV), and sharp spin-wave excitations at higher energies. Based on the observed dispersion relation in $SrFe_2As_2$, they estimated the exchange interactions to be $J_{1a} + 2J_2 \approx$100 meV, with out of plane coupling $J_z \approx$ 5 meV. On warming across T_N, the low-temperature spin gap rapidly closes, with weak critical scattering and spin-spin correlations in the paramagnetic state. The antiferromagnetic order in $SrFe_2As_2$ is therefore consistent with a first order phase transition, similar to the structural lattice distortion.

Chao Cao et al. in 2008 reported the density functional theory calculations for the parent compound LaOFeAs of the newly discovered 26 k Fe-based superconductor $LaO_{1-x}F_xFeAs$. They found that the ground state is an ordered antiferromagnet, with staggered moment about 2.3μ_B, on the border with the Mott insulating state and fit the bands crossing the Fermi surface, derived from Fe and As, to a tight-binding

Hamiltonian using maximally localized Wannier functions on Fe 3d and As 4p orbitals. The model Hamiltonian accurately describes the Fermi surface obtained via first-principles calculations. Due to the evident proximity of superconductivity to antiferromagnetism and the Mott transition, they suggested that the system may be an analog of the electron doped cuprates, where antiferromagnetism and superconductivity coexist.

T. Yildirim in 2008 observed from first principles calculations, strong interactions between arsenic ions in iron-pnictides, the strength of which is controlled by the Fe-spin state in an unprecedented way. Reducing the Fe-magnetic moment, weakens the Fe-As bonding, and in turn, increases both intra and inter-plane As-As interactions, causing giant reduction in the c-axis. For $CaFe_2As_2$ system, this reduction of c-axis with the loss of the Fe-moment is as large as 1.4 Å, an unheard of giant coupling of local spin-state of an ion to its lattice. Since the calculated large c-reduction has been recently observed only under high-pressure, these results suggest that the iron magnetic moment should be present in Fe-pnictides at all times at ambient pressure.

L. Boeri et al. in 2008 studied the electron-phonon coupling of the newly-discovered superconductor $LaO_{1-x}F_xFeAs$ from first-principles, using Density Functional Perturbation Theory. For the F−doped compounds, they predict even smaller coupling constants, due to the strong suppression of the electronic Density of States at the Fermi level. To reproduce the experimental T_C = 26 k, a 5-6 times larger coupling constant would be needed. These results indicate that electron-phonon coupling is not sufficient to explain superconductivity in the newly-discovered $LaO_{1-x}F_xFeAs$ superconductor, probably due to the importance of strong correlation effects.

Athena S. Sefat et al. in 2008 reported the crystal structure and numerous normal and superconducting state properties of layered tetragonal (*P*4/*nmm*) LaFeAsO, with F doping of ~ 11%. Resistivity measurements give an onset transition temperature T_C =

28.2 k, and low field magnetic susceptibility data indicate bulk superconductivity. In applied magnetic field, analysis of the resistive transition results in a critical field H_{c2} ~ 30 T and a coherence length ξ_{GL} ~ 35 Å. An upper limit for the electron carrier concentration of 1×10^{21} cm^{-3} is inferred from the Hall data just above T_C. Strong electron-electron correlations are suggested from temperature-dependent resistivity, Seebeck coefficient, and thermal conductivity data. Anomalies near T_C are observed in both Seebeck coefficient and thermal conductivity data.

Zi-Jian Yao et al. in 2008 explored spin fluctuations and unconventional superconducting pairing in Fe-based layer superconductors based on an effective two-band model and using the fluctuation-exchange (FLEX) approach. It is elaborated that one type of interband antiferromagnetic (AF) spin fluctuation stems from the interband Coulomb repulsion, while the other type of intraband AF spin fluctuation originates from the intraband Coulomb repulsion. Due to the Fermi-surface topology, a spin-singlet extended s-wave superconducting state is more favorable than the nodal d_{XY} -wave state if the interband AF spin fluctuation is more significant than the intraband one, otherwise vice versa. It is also revealed that the effective interband coupling plays an important role in the intraband pairings, which is a distinct feature of the present two-band system.

H. Nakamura et al. in 2008 reported that a puzzle in the iron-based superconductor $LaFeAsO_{1-x}F_x$ is that the magnetic moment obtained by first-principle electronic structure calculations is unexpectedly much larger than the experimentally observed one. For example, the calculated value is ~ 2.0 μ_B in the mother compound, while it is ~ 0.3 μ_B in experiments. They found that the puzzle is solved within the framework LDA + U by expanding the U value into a slightly negative range. We show U dependence of the obtained magnetic moment in both the undoped x = 0.0 and doped x = 0.125. These results reveal that the magnetic moment is drastically reduced when entering to the

slightly negative range of U. Moreover, the negative U well explains other measurement data, e.g., lattice constants and electronic DOS at the Fermi level.

T. Nomura et al. in 2008 experimentally observed that the anomaly in the ρ–T curve of the undoped LaFeAsO is associated with the crystallographic phase transition between the tetragonal (*P4/nmm*) and orthorhombic (*Cmma*) phases. The transition starts to occur at ~160 k, in agreement with a kink in the anomaly. The temperature is a little higher than that of the magnetic transition. The magnetic moments of Fe in the orthorhombic phase exhibit a predominantly antiferromagnetic order, forming the spin stripe type configuration in the layer. Both transitions can be explained by spin configuration dependent potential energy surfaces derived from the *ab initio* calculations.

I. R. Shein and A. L. Ivanovskii et al. in 2009 analyzed that for LnFeAsO system, atoms of the Fe sublattice form the system of covalent (Fe–As), ionic (Fe–As), and metallic (Fe–Fe) bonds inside the [FeAs] layer and participate (inside [FeAs] layers) in ionic interaction with the neighboring layers. Atoms of the As sublattice form the system of covalent (As–Fe) and ionic (As–Fe) bonds inside the [FeAs] layer and participate (inside [FeAs] layers) in ionic interaction with the neighboring layers. Atoms of the As sublattice form an additional system of covalent (As–Ln) interlayer bonds. Atoms of the rare earth metal sublattice form the system of covalent (Ln–O) and ionic (Ln–O) bonds inside the [LnO] layer and the system of covalent (Ln–As) interlayer bonds and participate (inside [LnO] layers) in ionic interaction with the neighboring layers. Atoms of the O sublattice form the system of covalent (O–Ln) and ionic (O–Ln) bonds inside the [LnO] layer and participate (inside [LnO] layers) in ionic interaction with the neighboring layers.

T. Yildirim in 2009 have revealed surprisingly strong As-As interactions in iron pnictides. The strength of this interaction is controlled by the Fe-As chemical bonding.

Reducing the Fe-moment reduces the Fe-As bonding, which in turn increases the As-As interaction along the z-axis, causing arsenic atoms on opposite sides of Fe-square lattice to move towards each other. This explains the high sensitivity of the z-atom positions and the large reduction of the c axis with the loss of Fe-magnetic moment. They showed that under external pressure, the high Fe-spin AF structure (i.e., stripe phase) should transform to a new structure with low Fe-spin state and significantly reduced c axis.

Jeffrey W. Lynn et al. in 2009 reported neutron scattering investigations of the crystal structures, magnetic structures, and spin dynamics of the iron-based RFe(As, P)(O, F) (R = La, Ce, Pr, Nd), (Ba,Sr,Ca)Fe_2As_2, and Fe_{1+x}(Te–Se) systems. On cooling from room temperature all the undoped materials exhibit universal behavior, where a tetragonal-to-orthorhombic/monoclinic structural transition occurs, below which the systems become antiferromagnets. For the first two classes of materials the magnetic structure within the a–b plane consists of chains of parallel Fe spins that are coupled antiferromagnetically in the orthogonal direction, with an ordered moment typically less than one Bohr magneton. Hence these are itinerant electron magnets, with a spin structure that is consistent with Fermi-surface nesting and a very energetic spin wave bandwidth ~ 0.2 eV. With doping, the structural and magnetic transitions are suppressed in favor of superconductivity, with superconducting transition temperatures up to ~ 55 k. Magnetic correlations are observed in the superconducting regime, with a magnetic resonance that follows the superconducting order parameter just like the cuprates. The rare earth moments order antiferromagnetically at low *T* like 'conventional' magnetic superconductors, while the Ce crystal field linewidths are affected when superconductivity sets in.

K. Haule and G. Kotliar in 2009 showed, using microscopic theory, that the normal state of the iron pnictides at high temperatures is highly anomalous, displaying a very enhanced magnetic susceptibility and a linear temperature dependence of the resistivity.

Below a coherence scale, the resistivity sharply drops and susceptibility crosses over to Pauli-like temperature dependence. Remarkably, the coherence-incoherence crossover temperature is a very strong function of the strength of the Hund's rule coupling J_{Hund}. On the basis of the normal state properties, we estimate J_{Hund} to be ~ 0.35 eV. In the atomic limit, this value of J_{Hund} leads to the critical ratio of the exchange constants J_1/J_2 ~ 2. While normal state incoherence is in common to all strongly correlated superconductors, the mechanism for emergence of the incoherent state in iron-oxypnictides, is unique due to its multiorbital electronic structure.

M J Calderón et al. in 2009 studied the dependence of the electronic structure of iron pnictides on the angle formed by the arsenic–iron bonds. Within a Slater–Koster tight binding model which captures the correct symmetry properties of the bands, they show that the density of states and the band structure are sensitive to the distortion of the tetrahedral environment of the iron atoms. This sensitivity is extremely strong in a two-orbital (d_{xz} , d_{yz}) model due to the formation of a flat band around the Fermi level. Inclusion of the d_{xy} orbital destroys the flat band while keeping considerable angle dependence in the band structure.

R. Osborn et al. in 2009 performed Measurements of the spin and lattice dynamics on non-superconducting ‘parent’ compounds based on the LaFeAsO (‘1111’) and $BaFe_2As_2$ (‘122’) crystal structures, and on electron and hole-doped superconducting compounds, using both polycrystalline and single crystal samples. Neutron measurements of the phonon density-of-state, subsequently supported by single crystal inelastic x-ray scattering, are in good agreement with *ab initio* calculations, provided the magnetism of the iron atoms is taken into account. However, when combined with estimates of the electron-phonon coupling, the predicted superconducting transition temperatures are less than 1k, making a conventional phononic mechanism for superconductivity highly unlikely. Measurements of the spin dynamics within the spin density wave phase of the parent compounds show evidence of strongly dispersive spin

waves with exchange interactions consistent with the observed magnetic order and a large anisotropy gap. Antiferromagnetic fluctuations persist in the normal phase of the superconducting compounds, but they are more diffuse.

R.S. Meghwal et al. in 2009 studied the extended two-band s–f model with additional terms, describing intersite Cooper pairs' interaction between 4f (5f) and conduction electrons. Following Green's function technique and equation of motion method, self-consistent equations for superconducting and magnetic order parameter are derived. The expressions for specific heat, density of states, and free energy are also derived. The theory has been applied to explain the coexistence of superconductivity and ferromagnetism in hybrid rutheno-cuprate superconductors $RuSr_2RECu_2O_8$ (RE = Gd, Eu). The theory shows that it is possible to become superconducting if the system is already ferromagnetic.

J. Fusayoshi et al. in 2009 studied Superconductivity in the cuprate oxide by Kondo-lattice theory based on the *t–J* model with the electron–phonon interaction arising from the modulation of the superexchange interaction by phonons. The self-energy of electrons is decomposed into the single-site and multisite self-energies. It is proved by using the mapping of the single-site self-energy in the *t–J* model to its corresponding one in the Anderson model that the single-site self-energy is simply that of a conventional Fermi liquid, even if a superconducting order parameter appears or the multisite self-energy is anomalous. The electron liquid characterized by the single-site self-energy is a conventional Fermi liquid. The Fermi liquid is further stabilized by the resonating-valence-bond (RVB) mechanism. The stabilized Fermi liquid is a relevant unperturbed state that can be used to study superconductivity and anomalous Fermi-liquid behaviors. The so-called spin-fluctuation-mediated exchange interaction, which includes the superexchange interaction as a part, is the attractive interaction that binds $d_{x^2-y^2}$-wave Cooper pairs.

B.K. Sahoo et al. recently in 2010 reported a phase diagram of superconductivity (SC) and antiferromagnetism (AF) for hole-doped cuprate superconductors in presence of chemical potential (μ) by using a model Hamiltonian. The Hamiltonian of the system is a mean field one and has been solved by writing equations of motion for the single particle Green functions. The expressions for appropriate single particle correlation function are derived. It is assumed that SC arises due to BCS pairing mechanism and AF order is simulated by staggered magnetic field in lattices of Cu–O planes. They get expressions for SC order parameter, AF order parameter and dopant concentration by using Green function technique of D.N. Zubarev and observed that a disordered phase appears after antiferromagnetism is destroyed in the range of very small doping. On further increase of the doping, the SC critical temperature first increases, attains a maximum value ($\simeq$ 39 k) and then decreases which agrees well with experimental observations for hole-doped cuprates. Their theoretical findings suggest that the AF coupling plays the vital role of the glue for the Cooper pairs.

S. Ishida et al. in 2010 found the Characteristic normal-state charge transport in the oxygen-deficient iron-arsenides $LnFeAsO_{1-y}$ (Ln: La and Nd) with the highest T_C's among known Fe-based superconductors. The effect of "doping" in this system is mainly on the carrier scattering, quite distinct from that in high- T_C cuprates. In the superconducting regime of the La system with maximum T_C = 28 k, the low-temperature resistivity is dominated by a T^2 term. On the other hand, in the Nd system with T_C higher than 40 k, the carriers are subject to stronger scattering showing T -linear resistivity and small magnetoresistance. Such strong scattering appears crucial for high- T_C superconductivity in the iron-based system.

Dao-xin Yao and E. W. Carlson in 2010 studied the magnetic excitations of undoped iron oxypnictides using a three-dimensional Heisenberg model with single-ion anisotropy. Analytic forms of the spin wave dispersion, velocities, and structure factor

are given. Aside from quantitative comparisons which can be made to inelastic neutron scattering experiments, they also gave qualitative criteria which can distinguish various regimes of coupling strength. They reported that the magnetization reduction due to quantum zero point fluctuations shows clear dependence on the c-axis coupling.