CHAPTER 1

INTRODUCTION AND OBJECTIVES

1.1. Introduction

Ferromagnetic materials exhibit a large magnetization even when the external magnetic field is removed. Weiss proposed the molecular field theory to explain such phenomenon. According to Weiss, there exist an internal molecular field which enforce the spontaneous magnetization of a ferromagnetic material. However, it is not possible to describe the origin of such internal field of strength lying in the range 10^6-10^7 Gauss by classical dipole which can describe only about 10^3 Gauss. In 1928, Heisenberg opined that such high value of internal field can be realized in terms of exchange interactions between the electrons, which is expressed by the well known Heisenberg Hamiltonian

$$\hat{H}_{exch} = -2J_{ij}\,\boldsymbol{S}_i \bullet \boldsymbol{S}_j\,. \tag{1}$$

where $\boldsymbol{S_i}$ and $\boldsymbol{S_j}$ represent the spin operators at the ith and jth sites respectively and J_{ij} represent the exchange coupling constant between the sites. The value of the coupling constants are found positive for ferromagnetic materials where strong exchange force between electrons on neighbouring sites tend to enforce a spatial ordering of their spin orientations parallel to each other. On the other, the coupling constants are found negative for antiferromagnetic materials which favour electronic spin at the neighbouring sites antiparallel to each other. In both the types of materials, the electronic spins are coupled. Consequently, it is not possible to flip one of them without affecting the others. Excitation of a single spin does not remain localized, rather it is shared by the total network of spins through an exchange interaction between them. Therefore, the excitation propagates through the spin system in a wave like form which is known as spin wave [1].

Bloch proposed that, in a spin system, low-lying excitations consist of propagating quantized spin deviations instead of a localized one [1]. In semi-classical picture, spin wave consists of arrangement spins precessing around the equilibrium direction with phase angle varies along the direction of propagation[2].To obtain the boson formalism, the spin operators are converted into boson operators through a transformation known as Holstein and Primakoff transformation [3]. This boson formalism allows one to calculate the thermodynamic properties of a magnetic system like magnon heat capacity and the variation of magnetization with temperature *etc.* [4].

Now, it has been observed that if one applies radio frequency (RF) magnetic field perpendicular to a static magnetic field, then magnons of uniform mode absorb energy from the RF magnetic field when its frequency matches with the frequency of the applied RF field. This phenomenon is known as Ferromagnetic resonance (FMR) [5-7]. The phenomenon of FMR can be detected thermally [8] or may be understood by studying the change in quasi-static properties of ferromagnetic materials, such as magnetoresistance [9-12], magnetoimpedance[13] and caloric properties due to FMR [14]. The FMR is also recognized as one of the most sensitive methods for the study of magnetic anisotropy [15-16].

It is also known that, with the increase in the power of the RF field, the phenomenon becomes quite different from those observed at low power level. The height of the absorption maximum decreases with the increase in power with observation of subsidiary absorption maxima [17-19]. It was first explained in a satisfactory way by H. Suhl [20]. In this case, certain modes, other than uniform mode, of magnons also become unstable due to the interaction with the uniform mode driven by the external magnetic field. For the first order process the frequency of the unstable mode is equal to half of the frequency of the uniform mode and for the second order process the frequency of the unstable mode is equal to the frequency of the uniform mode. As the number of magnons of uniform mode gradually increases, it is found to interact with other magnon modes and generate secondary degenerate magnons *via* two magnon relaxation processes. The secondary magnons so produced are also relaxed through three magnons and four magnons processes and produced magnons in turn relaxes until equilibrium is attained [21].

Along this direction, it is also known that when an RF field is taken parallel to the static magnetic field, certain modes of magnons with frequencies near the half of the frequency of the RF magnetic are get excited. This phenomenon is known as parallel pumping and was comprehensively explained by Schlomann and others [22-25]. As the magnons of different modes are coupled to each other, the absorbed energy is redistributed over the spectrum of magnons by the process of relaxation [26-29].

The above mentioned phenomena have applicability in microwave limiter and also in local heating of magnetic particles of small size. This local heating of magnetic particles finds an immediate application in the field of hyperthermic oncology [30-31]. Sakran *et al.*

have reported a rise in temperature of several degrees due to application of an RF field [8]. Recently, a number of literature came up using the pumping processes as it lead to Bose Einstein Condensation (BEC) of magnons at comparatively higher temperature, even at room temperature [32-35]. As the temperature (*T)* of a boson gas decreases at a given density of particles (*N)*, or the particle density *N* increases at a given temperature *T*, the chemical potential μ describing the gas, increases as well. BEC of magnons takes place if the density of the particles in the system is larger than the critical density defined by the condition $\mu(N,T)=\varepsilon_{\min}$, $\varepsilon_{\min}$ being the minimum magnon energy [35].

The phenomenon of superconductivity, discovered by Kamerlingh Onnes [37], is a significant example of quantum effects operating on a macroscopic scale. A superconducting material has some peculiar properties like perfect diamagnetism [38], zero dc resistance [39], *etc*. The observation of Isotope effect signifies that lattice vibrations may play a vital role in bringing about the phenomenon superconductivity [40]. Gorter and Casimir put forwarded a two fluid model to explain this phenomenon [41]. London provided a phenomenological theory of the electromagnetic behaviour of superconductor based on the two fluid type concepts [42]. Microscopic theory of superconductivity proposed by Bardeen, Cooper and Schrieffer says that the superfluid is formed from pairs of electrons which are bound together by lattice polarization forces [43]. The microscopic theory explains essentially all the general features of superconductivity known at that time.

Recently, it has been found that the superconductivity in UGe_2, $ZrZn_2$ and URhGe is confined to ferromagnetic phase [44-46]. The well known BCS theory of superconductivity fails to account the origin of such ferromagnetic superconductivity. Machida and Ohmi gave the phenomenological theory of ferromagnetic superconductivity [47]. The coexistence of ferromagnetism and superconductivity in solids has been an interesting topic of research for long time [48-51]. Karchev put forwarded the theory of magnon exchange mechanism of ferromagnetic superconductivity assuming the electrons to be itinerant[52]. But it has been confirmed that the electrons in those substances has both localized and itinerant nature which raises questions in contradiction to the theory proposed by Karchev[53]. On the other hand, the coexistence of antiferromagnetism and superconductivity has also been observed in high temperature cuprate superconductors and also in iron pnictides superconductors and in some heavy fermion U or Ce based compounds [54-70]. Many researchers have made attempts to explain the phenomena but the mechanism behind these phenomena still remains unexplained.

1.2. Objectives

The objective of the present thesis is to study the spin wave instability and unconventional superconductivity in ferromagnetic and antiferromagnetic superconductors. In the thesis we study the following:

- The increase in temperature of a ferromagnetic substance in the presence of a static magnetic field, and also in a radio frequency (RF) field perpendicular to a static magnetic field.

- The rise in temperature of a ferromagnetic substance in the presence of an RF magnetic field parallel to a static uniform magnetic field.

- The formation of BEC in a magnon gas at a high temperature in the presence of parallel or perpendicular pumping.

- The ferromagnetic superconductivity in Uranium compounds arising from electron magnon interactions.

- The phenomenon of antiferromagnetic superconductivity in iron pnictides arising from electron magnon interactions.