We have analyzed a fermionic infinite-ranged quantum Heisenberg spin glass with BCS coupling in real space in the presence of a magnetic field. It has been possible to locate the transition line between the normal paramagnetic phase (NP) and the phase where there is a long range order corresponding to pair formation in sites (PAIR). The nature of the transition line is also investigated. This transition ends at $T_f$, the transition temperature between NP and spin glass phase (SG) where the static approximation and replica symmetry ansatz are reliable.

Keywords: Heisenberg Spin glass

The competition between the superconducting and spin glass ordering has been reported in cuprate superconductor [1], heavy fermions [2] and conventional superconductors doped with magnetic impurities [3]. Theoretical studies [4] in these later systems have been mainly interested in the calculation of the superconducting density of states by using a model composed by a conventional BCS interaction for the conducting electrons which interact with the localized magnetic impurities by a s–d exchange interaction.

In the present work the interplay between the mechanism responsible by the spin glass ordering and the BCS pairing among localized fermions of opposite spins has been investigated for the half filling case at mean field level. This has been done by using a Hamiltonian with a fermionic Heisenberg spin glass and a BCS pairing interaction in real space [5]. This model has been obtained from Ref. [4] tracing out by perturbation the conducting fermionic degrees of freedom.

We consider the Hamiltonian given by Eq. (A20) of Ref. [5] in the presence of a magnetic field $H_z$. The problem is formulated in the path integral formalism where the spins are represented by bilinear combinations of Grassmann fields and random coupling among the spins are infinite ranged with a Gaussian distribution with zero mean and variance given by Ref. [6]. The disorder is treated in the context of the replica method with an important difference compared with its classical counterparts: in the quantum case the diagonal component of the spin glass order parameter is no longer constrained to unity. In fact, the location of other transitions depends on this component even when the non-diagonal component is zero. The magnetic field in the $z$ direction separates the order parameters in two groups: transversal to the field and parallel to it [7]. The transversal non-diagonal spin glass order parameter is taken as null. The static approximations and the replica symmetry ansatz is used for the remaining order parameters. This procedure is reliable up to $T_f$ (the transition temperature between the spin glass (SG) and the normal-paramagnetic (NP) phases) which moves down as the field strength increases. Therefore, the Grand Canonical potential (details will be given elsewhere [8]) can be found for the half-filling case as

$$\Omega = 2\beta J^2(R^2 + R_z - Q_z) + \frac{g}{4}|\eta|^2 + \frac{1}{\beta}\int_{-\infty}^{+\infty} Dw \ln(I_\beta)$$

$$I_\beta = \int_{0}^{+\infty} uDu\int_{-\infty}^{+\infty} Dv[\cosh(\frac{\beta g}{2}|\eta|) + \cosh(\beta|\bar{h}|)]$$

where $\bar{h} = J\sqrt{2Rw^2 + \theta^2}$ and $\theta = [v\sqrt{2(R_z - Q_z)} + w\sqrt{Q_z} + H_z/(2J)]$. In both equations $Du = du\exp(-u^2/2)/\sqrt{2\pi}$ and $\beta = 1/T$ and $J$ is given by Eq. (3) of Ref. [5].

In Eq. (1), $|\eta|$ is the PAIR order parameter, $Q_z$ and $R_z$ are, respectively, the non-diagonal and the diagonal component of the spin glass order parameter parallel to the field $H_z$ and $R$ is the diagonal component transversal to it. The saddle point equations for $R$, $Q_z$, $R_z$ and $|\eta|$ follow from Eq. (1).

A phase diagram can be obtained in $T$ – $g$ ($g$ is the pairing strength) space for different values of $H_z$ by solving the resulting equations for $R$, $Q_z$, $R_z$ and $|\eta|$ (see Fig. (1)).

![FIG. 1. Phase diagram as a function of temperature and pairing coupling $g/J$ for two values of $H^*$ where $H^* = H_z/J(8)^{1/2}$. Solid lines indicate second order transitions while dotted lines indicate a first order transition. Tricritical points are shown as filled squares.](image-url)
If $H_z = 0$, for high $T$ and small $g$ there is no long range order ($|\eta| = 0$) that corresponds to NP phase. For high $T$ and $g$, $|\eta| \neq 0$ which corresponds to the PAIR phase. For the transition line, it has been found a crossover from a continuous behavior to a sharp one at $(T_{tc}, g_{tc})$. The changing in the behavior of $|\eta|$ is shown in Fig. (2).

The parameter $Q_z$ is null and $R = R_z$ shows a crossover from continuous to discontinuous behavior as $|\eta|$ does. If $H_z \neq 0$, the PAIR phase only exists for larger values of $g$. The point $(T_{tc}, g_{tc})$ is moved up and the region where the transition is the first order type increases. The nature of $(T_{tc}, g_{tc})$ as a tricritical point has been confirmed by following the same procedure of Ref. [5]. The behavior of $R$, $R_z$ and $Q_z$ changes strongly as shown in the Fig. (3).

The temperature $T_f$ can be found from the expansion of the Grand Canonical potential up to the quadratic term of the non-diagonal component transversal to the field of the spin glass order parameter [7]. The condition that the coefficient of the quadratic term vanishes gives $T_f/J = 4R$ (in the static approximation) which must be solved with the equations for the order parameters.

To conclude, this work has analyzed a fermionic Heisenberg spin glass model with a BCS pairing among local fermions which has been solved by reduction to a one site problem. A transition line separating the NP and PAIR phases has been obtained having a tricritical point depending on $H_z$ from where second order transition occurs for higher values of $g$ and first order transition occurs for lower values of $g$.

FIG. 3. Same as Fig. 2 for $H^*/J = 0.75$.

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