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Thermal Effects and Competition Between Magnetic Phases in Some Spin Glass Aufe Alloys

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□ ABSTRACT □

According to use of nano (10^{-9}) dimensions in modern experimental techniques, thermal transition investigations carried out on AuFe spin glass alloys, with concentration range (0.1% - 15% per magnetic impurity), and thermal spectrum (0.01- 300 K). Because there is no one source that can give all exact experimental information, we got data from many resources (resistivity, specific heat, susceptibility, Mossbauer effect, neutron scattering, magnetization and hysteresis cycles, NMR, SR),and obtain a new experimental thermal magnetic phase diagram . A conflict with theoretical studies has been found, because spin glass theory is a new theory and has not yet complete.

The aim of this search is to compare between tow era, modern nano era, and old micro era technology, in no doubt, nano technology will give fine data, and hyperfine information.

Key Words: Spin glass, Thermal, Magnetic, Phase Diagram

PACS: 75:10, 75:30, 75:40, 75:50.

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الآثار الحرارية والتنافس بين الأطوار المغناطيسية في بعض خلائط الزجاج السبيني الثنائية (ذهب – حديد)

الدكتور محمد أحمد آلجلالي*

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□ الملخّص □

في إطار دخول التقنيات التجريبية الحديثة مرحلة أبعاد العينات من مرتبة النانو (10^{-9})، جرت اختبارات التحول الحراري على خلائط ذهب-حديد ، في المجال التركيزي (0.1% – 15%) للشائبة المغناطيسية، والمجال الحراري(0.01 – 300 كلفن) ،ونظرا لاستحالة الحصول على كافة المعلومات من مصدر تجريبي واحد، ووفق عدة مداخل تجريبية[المقاومية الكهربائية،السعات الحرارية، الطواعية(الحساسية)المغناطيسية، أثر موسباو، انتثار النيترون، التمغنط ودورة البطاء المغناطيسي]، تم دراسة ورسم مخطط الطور المغناطيسي الحراري بين تغيرات درجات الحرارة وتركيز الشائبة المغناطيسية في الخليطة، أعطت الدراسة منظورا جديدا للتحولات لا يتوافق مع الدراسات النظرية بشكل دقيق، وذلك بسبب أن نظرية الزجاج السبيني الحديثة العهد لم تكتمل بعد.

يهدف البحث إلى إظهار دور تقنية النانو في الأبحاث الحديثة حيث أن هذه التقنية تعطي معلومات فائقة الدقة ونتائج أكثر وطوحا بالمقارنة مع التقنيات السابقة (تقنية المايكرو 10^{-6}).

الكلمات المفتاحية: الزجاج السبيني- حراري- مغناطيسي- مخطط الطور
PACS: 75:10, 75:30, 75:40, 75:50.

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Introduction:

Spin glass is (a new magnetic) system discovered in 1972 [1]. That is from a sharp cusp in magnetic susceptibility which showed at characteristic temperature called spin freezing temperature. This system consist of local 3d or 4f magnetic impurities in non-magnetic matrix, impurities are distributed randomly where sites and bonds randomness, and interactions between the two ferromagnetic and antiferromagnetic regimes are competitive, which leads to an inability to make a spin arrangement achieves a minimum energy to bond energy. This leads to the frustrations in the interactions that is the most important feature that distinguishes this regime.

The Ruderman – Kittel – Kasuya - Yosida (RKKY) interactions, being an indirect exchange interactions of localized spins via conduction electrons, is one of the important mechanisms explaining the origin of magnetism in some solids and distinguish between spin glasses and another magnetic systems . So far, it has been considered in the bulk (3D) and planar (2D) structures [1,2], in the theoretical systems with arbitrary dimensionality [3,4] and in multilayer materials[5,6,7]. Spin glass theory evolved dramatically and extended to study the mechanism of action of the biological system (neural networks, development, brain work, and proteins), and industrial system and computer sciences (artificial brain and all modes of records and storage of relevant information with very high capacity). In physics, this system has a modern scientific challenge to all the specialists in physicists and mathematicians either at the theoretical level or at the experimental one.

Methodology And Material

we can divide this part to tow points:

a. Theoretical Background

The model of (Edwards-Anderson) EA [3] was the first theoretical one describing the state of spin glass according to the following Hamiltonian:

$$\mathrm{H} = \sum_{\langle i,j \rangle} J_{ij} S_i . S_j \qquad \textbf{(1)}$$

Where S_i is the spin in position i, S_j is the spin in position j and J_{ij} is exchange constant and related to the energy of RKKY interaction:

$$J(R_{ij}) = \frac{9\pi n^2}{E_F} J_{sd}^2 \frac{x\cos x - \sin x}{x^4} \qquad \textbf{(2)}$$

Where$\left(x = 2k_F R_{ij}\right)$, { $J_{ij} = J\left(R_i R_j\right) = J(R_{ij}$}, EA has described the system through an order parameter carries qualities of remembrance (memory) at its freezing temperature as follows :

$$\begin{aligned} & q_{EA}(t) = \left\langle S_i\left(t\right).S_i\left(0\right)\right\rangle \\ & when \quad T \le T_f \Rightarrow q_{EA} \ne 0 \\ & and\ when \quad T \ge T_f \Rightarrow q_{EA} = 0 \end{aligned} \qquad \textbf{(3)}$$

According to this analysis, we can distinguish three models through magnetization where ($M = \langle S_i \rangle$)) and parameter order (q), these models are namely:

1. Model of paramagnetic, where (M=0 and q=0).
2. Model of spin glass, where (M=0 and q ≠ 0).
3. Model of ferromagnetic where (M ≠ 0 and q ≠ 0).

According to this theoretical model, the magnetic susceptibility and specific heat capacity show phase shift at the spin freezing temperature, EA type followed by the model of SK(Sherrington & Kirkpatrick)[4], which depends at mean magnetic field theory and the replica symmetric method, the model of SK predicted that phase transition has a sharp maximum of each of magnetic susceptibility and specific heat capacity at the freezing temperature, and arrived at a negative value of entropy at low temperatures. This model could not give a good interpretation to this anomalies phenomena. Figure (1) shows the outline theoretical magnetic phase diagram, according to SK theory. Subsequent models meet multiple times and at other times conflicted with the model SK [5], and in parallel with the above model, phenomenological model appears [6], which examines the phenomenon through spin relaxation times and their relationship with the temperature according to the following two relationships of Arrhenius and Vogel-Fulcher:

$$\tau = \tau_0 \exp\left(\frac{E_a}{K_B T_f}\right)$$

$$\tau = \tau_0 \exp\left(\frac{E_a}{K_B (T_f - T_o)}\right) \qquad \textbf{(4)}$$

Where, $\tau_0 = 10^{-11}$ sec, T_0 is the temperature at which RKKY interactions are almost complete and E_a is activation energy, and this model has given results exceeded the theoretical description [7], and proved that the spin glass system does not pass through phase transformation but is in the similar situation of viscosity in ordinary glass.

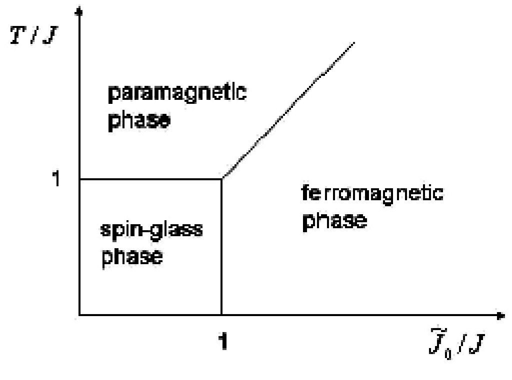


Fig.(1):Theoretical magnetic phase diagram of spin glass regime

(Chiu Fan Lee and Neil F. Johnson , ar Xiv: quant-ph/0412069 v1 8 Dec 2004)

b. Empirical Facts

Experimental results show that spin glass alloys pass through very complex stages during exposure to gradually thermal changes, it does not reach to the phase of being stable like other magnetic systems, These are characterized by entering into a new independent system that preceded or followed at a specific temperature such as Curie temperature in ferromagnetic or Neel temperature for antiferromagnetic for example. Even how to access the temperature of spin freezing not agree with different experimental tracks. The following summary shows some of the results reached by the experiments about the deal in the process of entering the alloy in spin glass phase and different interpretations around it :

a. The path of the electrical resistivity and the specific heat capacity appears as a broad maximum does not give any indications to a phase shift in with reducing in temperature [8].

b. The magnetic susceptibility path which appears sharp cusp maximum at a transition temperature named spin freezing temperature; we think that it is a threshold turning a new unstable phase transition called a spin glass system [9].

c. The dynamic tracks dominated by thermal transformations through super precision studies, showed that there was no phase transition in the spin glass system. Figures (2) and table (1) show some of those tracks, and relaxation times approval to spin freezing temperatures [10].

d. The track of the magnetic field effects that is concerned with thermal transformations with or without external magnetic fields, this track may give very long relaxation times with refrigeration technology and with the existence of magnetic field or not (field cold & zero-field cold)[11].

e. The track of magnetic phase diagrams tried to show the magnetic behavior in a variety of ways, but what was published was not based on the comprehensive treatments like we are, and the Figure (3) shows one of these treatments, the alloys of (AuFe) [12].

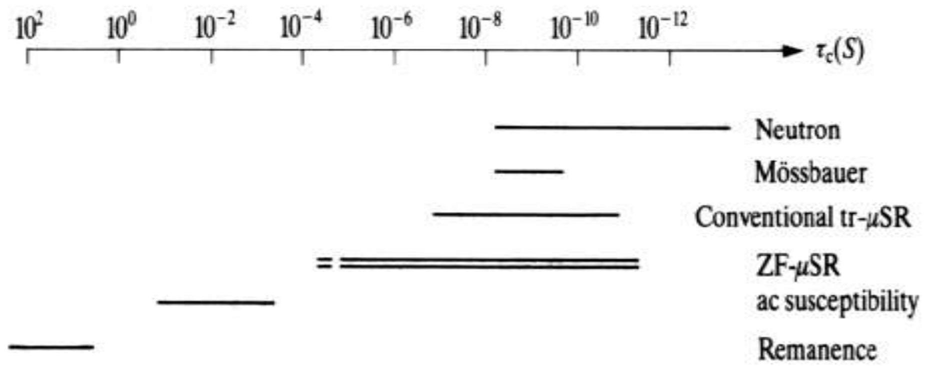


Fig.(2): windows to see spin glass dynamical of deferent relaxation times (after Uemera,et.al,1985)

Table (1): shows the relaxation times that correspond to different freezing temperatures by mode of study, which is the discovery of freezing (after Atsuko ito, 2000).

Method	Time-scale (sec)	Space-scale
Magnetization	$10^{-2} \sim \infty$	bulk
Ac-susceptibility	$10^{-6} \sim 10^{5}$	bulk

Mössbauer	$10^{-9} \sim 10^{-6}$ (^{57}Fe)	Single atom
Neutron scattering	$10^{-11} \sim 10^{-9}$	>50 A^{o}
μ^{+} SR	$10^{-11} \sim 10^{-5}$	10 – 100 lattice unit

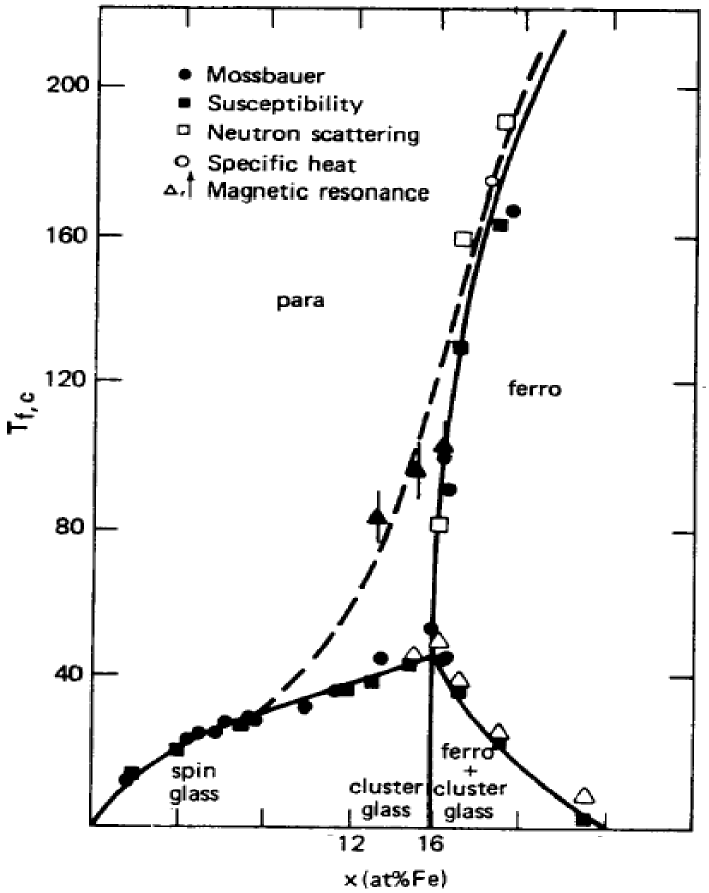


Fig.(3):experimental magnetic phase diagram to AuFe alloy according to micro techniques (after D.Sherrington,2004)

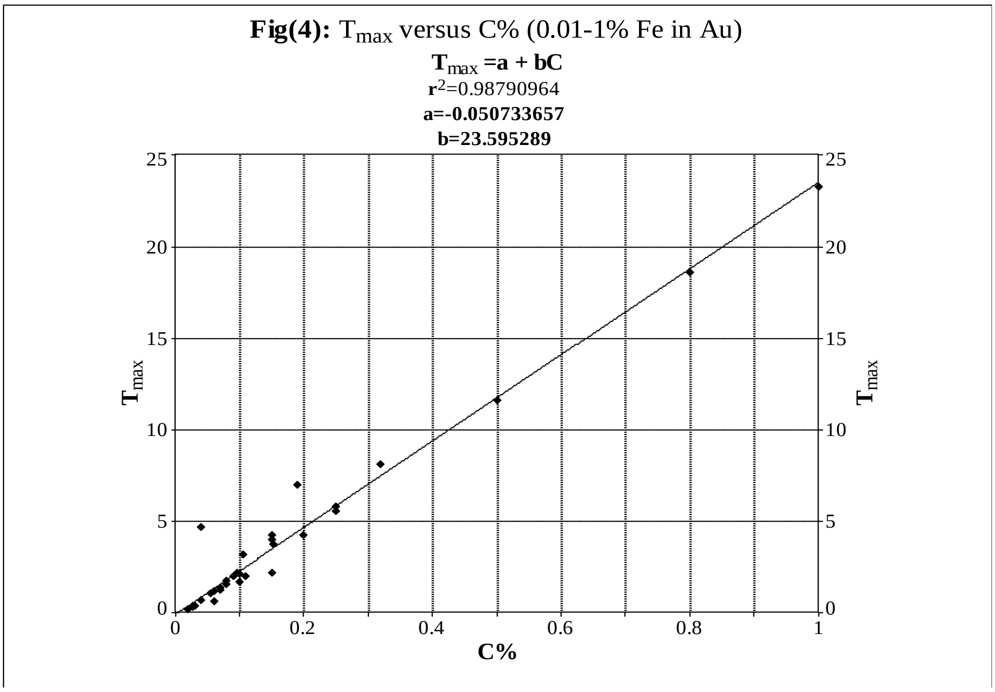
Results and Discussion:

At the outset the experimental results has been monitoring all tracks in the preceding paragraph to describe an integrated phenomenon, and dealt with according to the program (Table curve 2D v.5) to obtain appropriate mathematical relationships between temperature and the concentration of the magnetic impurities, in accordance with the following :

1. The experimental points show that the electrical resistivity and specific heats (thermal capacities) have a broad maximum extended to long range of temperatures, showed no appearance of a phase transformation. By comparing that with the results of magnetic susceptibility χ it is found that the alloy in that thermal area subject to curie's law

$$\chi = \frac{c}{T} \qquad \textbf{(5)}$$

Where c is Curie constant. This confirms that this system in paramagnetic phase (PM). The two figures (4-5) showed better fit between the temperature of the maximum resistivity and concentration of the magnetic impurities .Where such Fig. (4) for an ideal spin glass and Fig. (5) for a real spin glass [7, 20] and that according to the amount of magnetic impurity concentration.



Fig(4): T_{max} versus C% (0.01-1% Fe in Au)

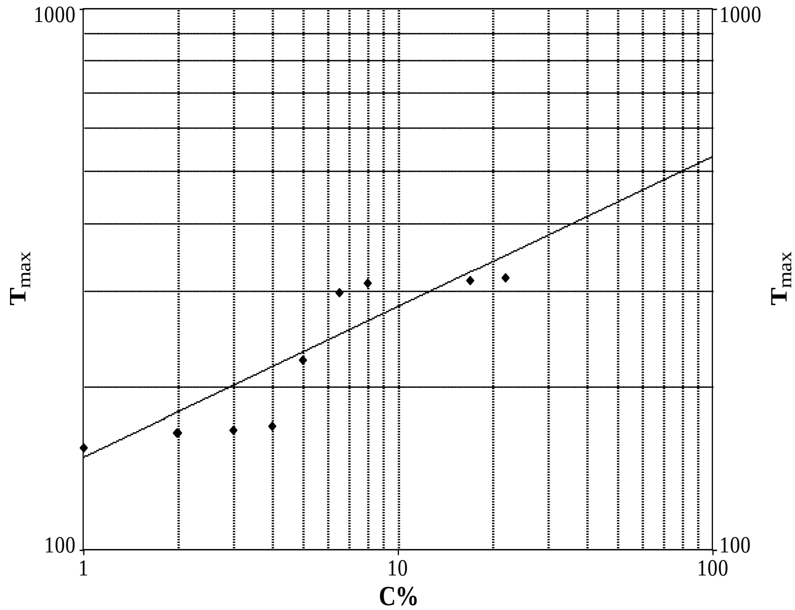
Fig(5): $\mathbf{T}_{max}$ versus C% (1-10% Fe in Au)

$\ln T_{max} = a + b \ln C$

r^2=0.93238260

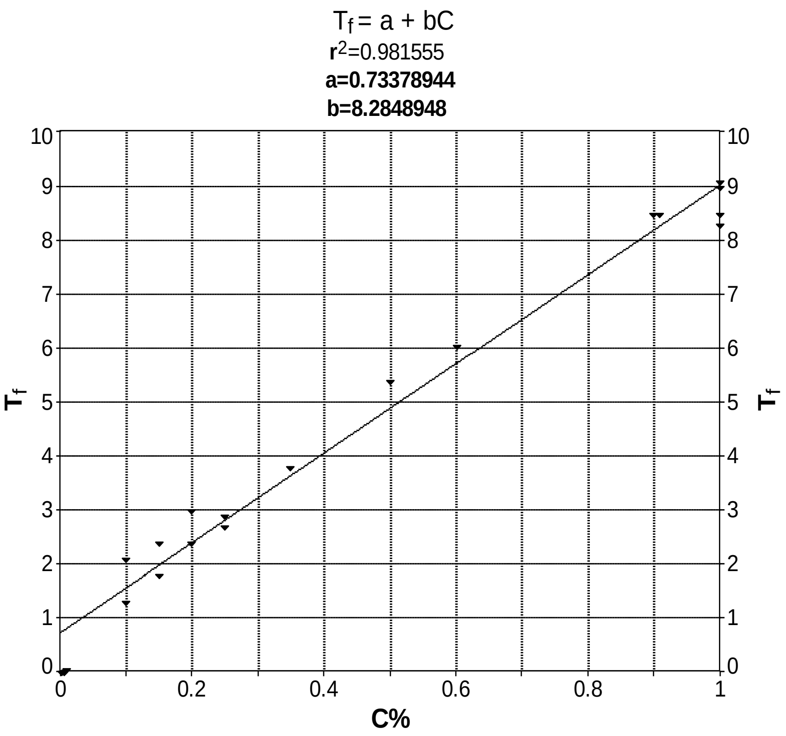
a=5.0047195

b=0.27814168

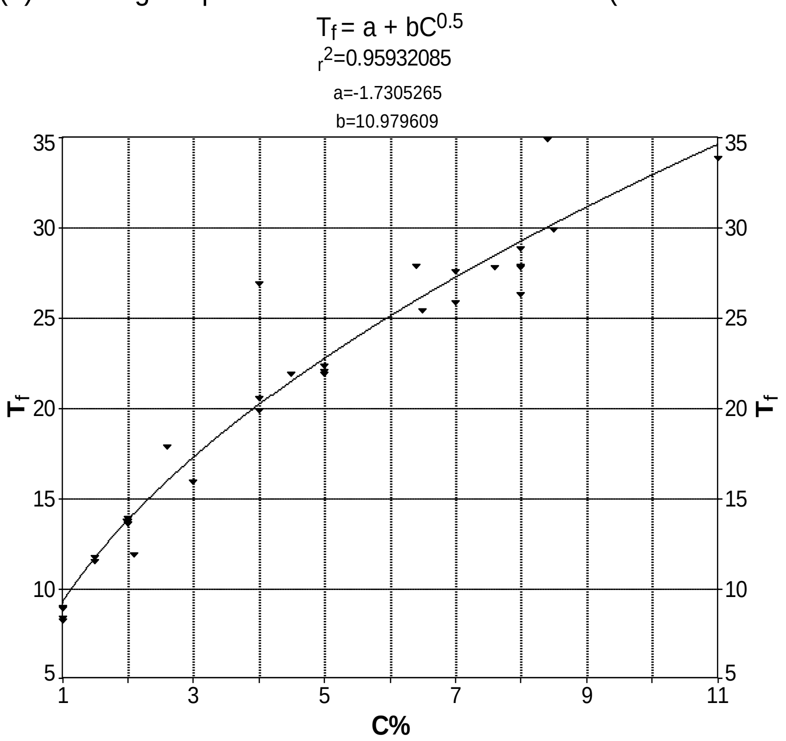


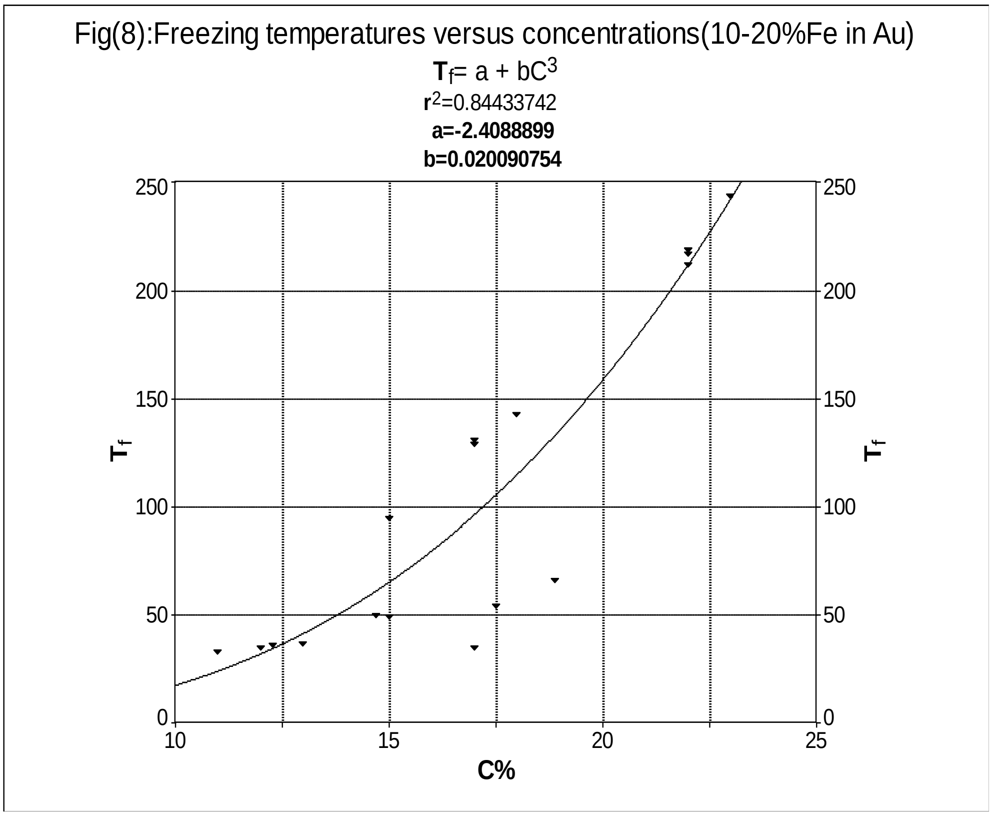
2. At temperatures lower than the previous one the magnetic susceptibility denotes to sharp cusp maximum in its value, we think it is the beginning of a turning point, a new phase transition happening at which spin glass occurred. This turning point has named the spin freezing temperature (T_f). Fig (6) shows the spin freezing temperatures as a function of the concentration of magnetic impurities in concentration range (0.01 - 1%). Fig (7) shows the focused area in concentration range (1-10%) as well as the theoretical relationship event for each. Figure (8) shows clear scattering in the dependence of spin freezing temperature on the concentration, where we exceed the concentration ratio of the spin glass system which is called here re-entry (reentrant) in spin glass regime [12]or the mixed system (micto-magnetic) of spin glass with ferromagnetic (SG+FM) shown in Figure (12). This is a new trend gateway for a spin glass formation in high temperatures and therefore to inter to the scope of commercial competition for all electronic devices.

Fig(6):Freezing temperatures versus concentrations (0.01-1% Fe in Au)



Fig(7):Freezing temperatures versus concentrations (1-10% Fe in Au)





3. In the area of separation between the maximum of resistivity (T_{max}) and the spin freezing temperature (T_f) and in magnetic impurity concentration higher than 1% the experimental results showed the presence of temperature of Curie or Neel (T_c), which is evidence of the existence of exchange interaction between magnetic impurities and magnetic susceptibility χ subject to the law of Curie - Weiss :

$$\chi = \frac{C}{T - T_c} \qquad \textbf{(6)}$$

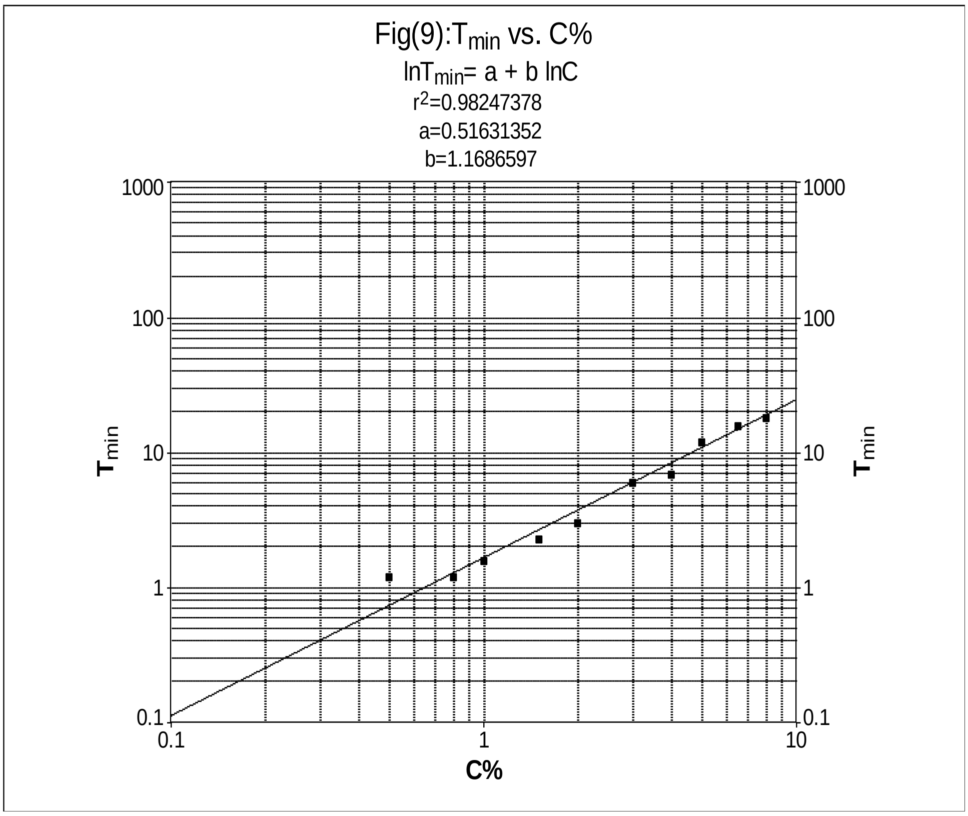
Where, $T_c = C\lambda$, and λ is a temperature independent constant, which inconsistent with EA and SK theories where the theory supposed the system enter directly from the paramagnetic (PM) to a glass spin (SG). And here we agree with the theory of Wolfarth [13] or the so-called theory of clusters (groupings), which has claimed responsibility the model of Neel [14] for the free clusters (Grapes), but without any interactions between those clusters (grapes), which will give a status similar to the paramagnetic, but by the clusters system and not by a singular spin especially in the case of low concentration. This phenomenon called super paramagnetic (SPM). It is assumed that the interactions among cluster are direct interactions (d-d). In the iron impurity is ferromagnetic (FM) and in the manganese impurities is antiferromagnetic (AFM). Increasing impurity level increases the interactions to start a semi-ferromagnetic phase shows the temperature of Curie or Neel. This is the reason, as we believe, why experimentally this temperature appears.

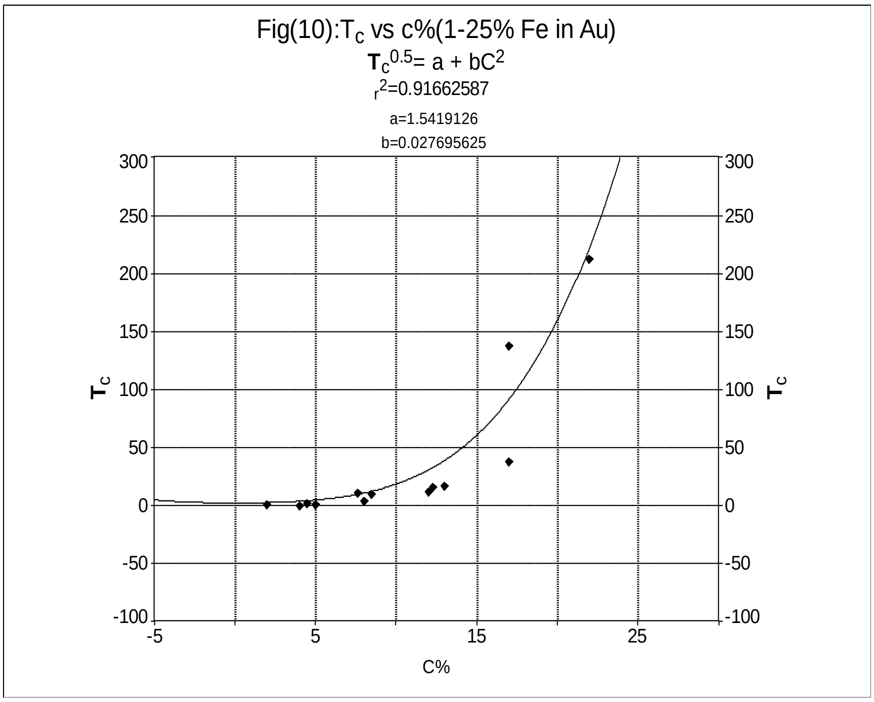
4. At temperatures (T_{min}) more lower than the spin freezing temperature, Figure (9), a phase transition occurs through the emergence of spin waves which detected by experimental studies of resistivity and magnetic specific heat and through theoretically appropriate fit to the following of resistivity and specific heat

$$\Delta\rho = \rho_0 + AT^{3/2}$$
$$\Delta C = b\frac{d}{dT}(\Delta\rho.T) \quad \textbf{(7)}$$

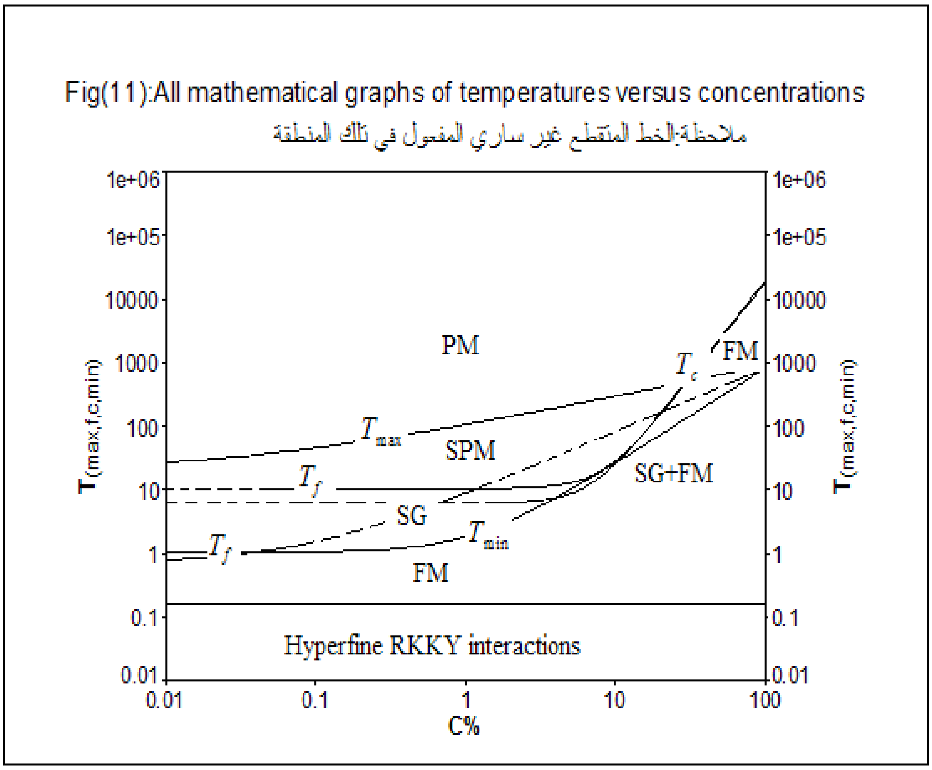
Where (ρ_0) is the residual resistivity, (A, b) are constants related to the concentration. The theory of RA [16] has supported this attitude and treatment the issue of the spin fluctuations with long waves which suggests that the system had entered into semi-ferromagnetic, which emphasizes the appearance of Curie and Neel temperature (T_c) at that range of temperature. From Fig (10) it is noted that these temperatures are positive (Curie temperature). It is evidence that the system trying to be in the phase of ferromagnetism.

5. A great accuracy (hyperfine) studies [17] show that the spin freezing temperature, which discovered from the study of magnetic susceptibility, can appear above and below this temperature approved different relaxation times, which shows that this temperature is not a temperature of phase transition, but the situation is a sudden turning for the relaxation times to become very long (the memories) [18].





6. At very low temperature, under half Kelvin, the interactions of hyperfine RKKY interactions begin, and the nucleus participate in new type of spin glass (nuclear memories) . Figure (11) shows a total mathematical treatment for each kind of temperatures as a function of the concentration and give us an overview of what is thermally happening within the alloy from the highest temperatures to the lowest ones.



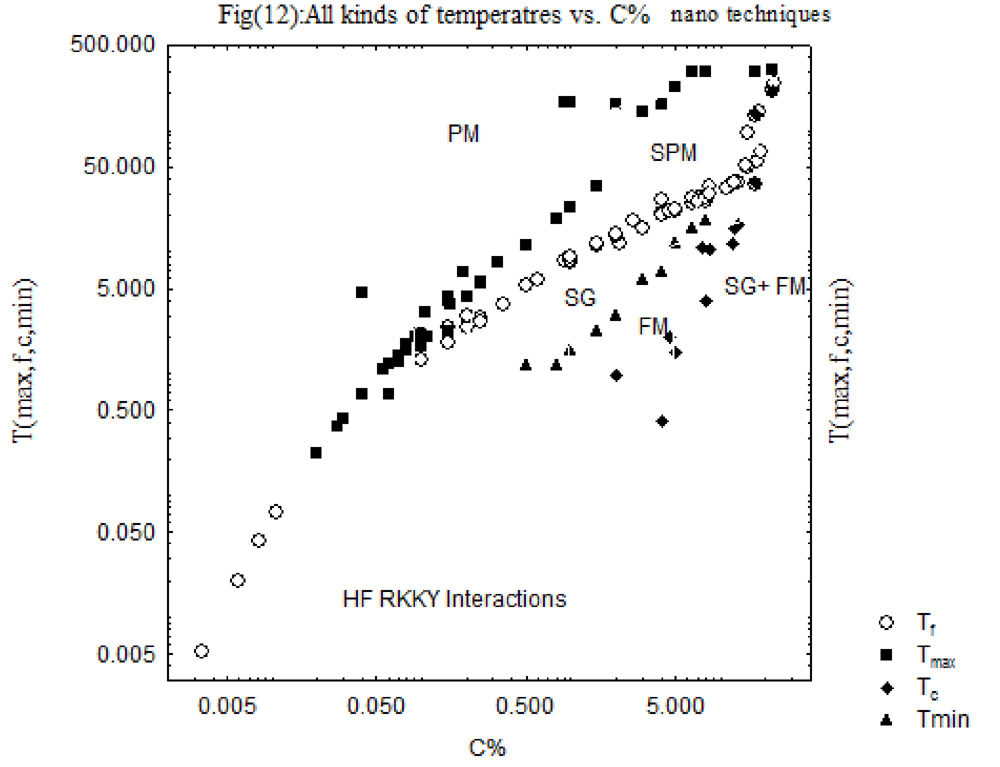
Conclusions and Recommendations:

Throughout the above, the studied alloys which show spin glass system must path through different stages:

1. Paramagnetic phase (PM).
2. Super paramagnetic phase (SPM)).
3. Spin glass Phase (SG) and distinguish two phases: the first, RKKY interactions between clusters, and the second, RKKY interactions between Single spins.
4. Semi-ferromagnetic phase (FM), which thermally followed the spin glass Regime (SG).
5. Mixed phase for concentration over 10% (Mictomagnetic).
6. Ferromagnetic phase for concentration over 20% (FM).
7. Stage of hyperfine indirect interactions which appear at under half Kelvin (Hyperfine-RKKY-interactions.)

Based on previous studies, all the real experimental points were plotted on the same figure by using the (statistica 7) program as shown in figure (12) of AuFe) alloy. The comparison between this figure and Figures (3) and (11) shows how important and extension of this study to give a new perception of the system needs to further theoretical study compared with the Figure (1), which supposed that the spin glass phase is being independent and unstable phase, while referring to the fact that the system is far from stability through different relaxation times of windows as in Figurers (2 & 3). These relaxation times correspond with different frozen temperatures, which underline the need to remove the depth topic contradiction between theory and experiment.

Fig(12):All kinds of temperatres vs. C%   nano techniques



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