Nuclear demagnetization →

Because nuclear magnetic moments are weak, nuclear magnetic interactions are much weaker than similar electronic interactions. We expect to reach a temp. 100 times lower with a nuclear paramagnet than with an electron paramagnet.

The initial temperature T_1 of the nuclear stage in a nuclear spin cooling experiment must be lower than in an electron spin-cooling experiment. If we start at $B = 50\ kG$ and $T_1 = 0.01\ K$, then

$$\mu B / k_B T_1 \simeq 0.5$$

and the entropy decrease on magnetization is over 10 % of the maximum spin entropy. This is sufficient to overwhelm the lattice and from

$$T_2 = T_1 (B_\Delta / B)$$

where B is the initial field.

now we estimate a final temp. $T_2 = 10^{-7}$ K. The first nuclear cooling experiment carried out on Cu nuclei in the metal, starting from a first stage at about 0.02 K as attained by electronic cooling. The lowest temp. reached was 1.2×10^{-6} K.

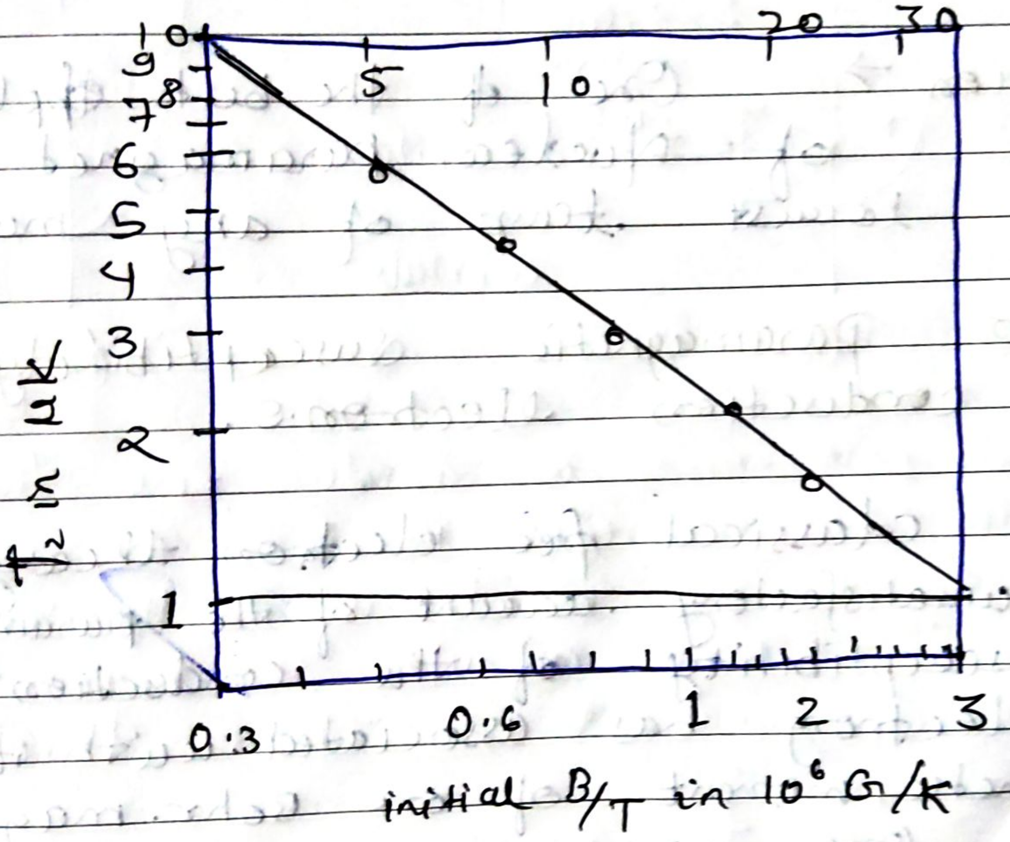

fig Nuclear demagnetization of Cu nuclei in the metal, starting from 0.012 K and various fields.

The results in above fig fit a line of the form of $T_2 = T_1(B_\Delta/B)$ as $T_2 = T_1(3.1/B)$ with B in gauss, so that $B_\Delta = 3.1$ Gauss. This is the effective interaction field of magnetic moments of the Cu nuclei. The motivation for using nuclei in a metal is that conduction electrons helps ensure rapid thermal contact of lattice and nuclei at the temperature of the first stage.

Application → One of the best application of Nuclear paramagnet is to obtain lowest temp of any metal.

Question (10) Paramagnetic susceptibility and conduction electrons.

Answer → Classical free electron theory gives an unsatisfactory account of the paramagnetic susceptibility of the conduction electrons. An electron has associated with it a magnetic moment of one Bohr magneton, μ_B. One might expect that the conduction electrons would make a curie - type paramagnetic contribution

$$\frac{M}{B} \cong \frac{N\,J(J+1)\,g^2\mu_B^2}{3k_BT} = \frac{N p^2 \mu_B^2}{3k_BT} = \frac{C}{T}$$

of the metal : $M = N\mu_B^2/k_BT$.

Instead it is observed that the magnetiza^n of most normal non-ferromagnetic metals independent of temperatures.

Pauli showed that the applica^n of fermi Dirac application of distribution, would correct the theory as required

Most conduction electrons in a metal, however, have no possibility of turning over when a field is applied, because most orbitals in the fermi sea with parallel spin array are already occupied. Only the electrons within a range k_BT of the top of the fermi distribution have a chance to turn over in the field; thus only the fraction T/T_F of the total number of electrons contribute to the susceptibility.

Hence.

$$M \simeq \frac{N\mu^2 B}{k_B T} \cdot \frac{T}{T_F} = \frac{N\mu^2}{k_B T_F} \cdot B$$

which is independent of temperature and of the observed order of magnitude.

We now calculate the expression for the paramagnetic susceptibility of free electron gas at $T \ll T_F$.

We follow the method of calculation suggested by below fig.

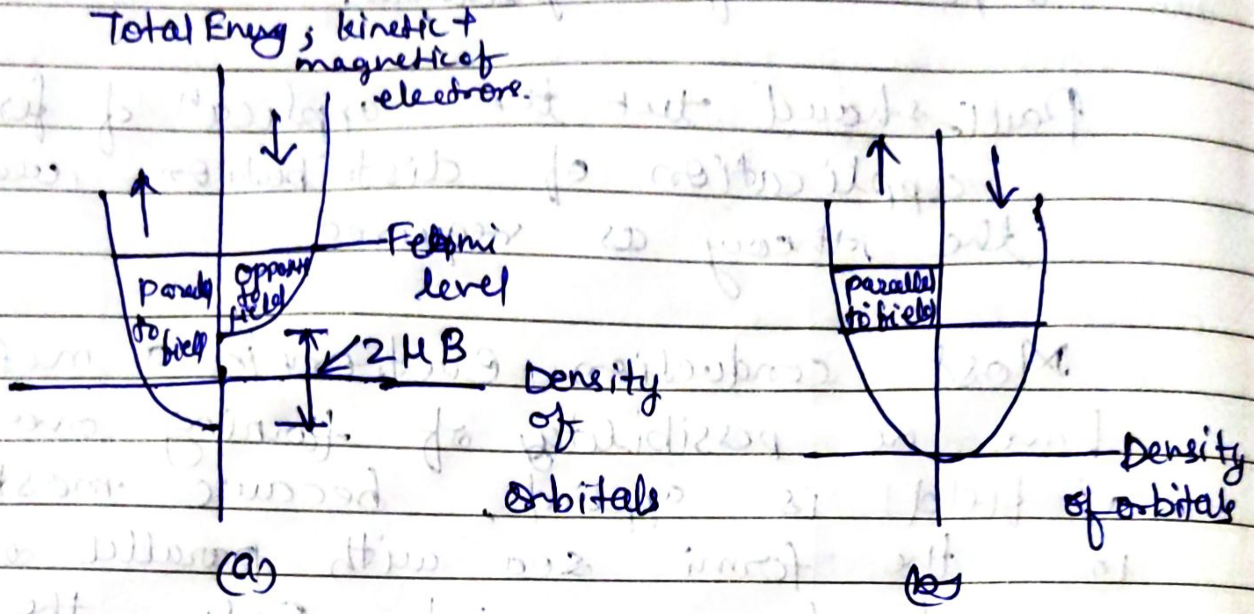

fig → Pauli paramagnet at absolute zero the orbitals in the shaded region in (a) are occupied. The number of electrons in the "up" and "down" will adjust to make the energies equal at the fermi level.

(b) we show the excess of moment up electrons in the magnetic field.

The concentration of electrons with magnetic moments parallel to the magnetic field is

$$N_{\uparrow} = \frac{1}{2}\int_{-\mu B}^{\epsilon_F} d\epsilon\, D(\epsilon + \mu B) \cong \frac{1}{2}\int_{0}^{\epsilon_F} d\epsilon\, D(\epsilon) + \frac{1}{2}\mu B D(\epsilon_F)$$

written for absolute zero. Here $\frac{1}{2} D(\epsilon + \mu B)$ is the density of orbitals of one spin orientation, with allowance for the downward shift of energy by $-\mu B$. The approximation is written for $k_B T \ll \epsilon_F$.

The concentration of electrons with magnetic moments antiparallel to the magnetic field is

$$N_- = \frac{1}{2}\int_{\mu B}^{\epsilon_F} d\epsilon\, D(\epsilon - \mu B) = \frac{1}{2}\int_0^{\epsilon_F} d\epsilon\, D(\epsilon) - \frac{1}{2}\mu B\, D(\epsilon_F)$$

The magnetization is given by $M = \mu(N_+ - N_-)$, so that

$$M = \mu^2 D(\epsilon_F)\cdot B = \frac{3N\mu^2}{2 k_B T_F}\cdot B, \quad \text{—(2)}$$

with $D(\epsilon) = 3N/2\epsilon_F = 3N/2k_B T_F$.

Above eqn (2) gives the pauli spin magnetization of conduction electrons.

Landau has shown that for free electrons wave function are modified. this cause a diamagnetic moment equal to $-1/3$ of the parallel magnetic moment. Thus the total magnetic moment magnetization of a free electron gas is

$$M = \frac{N\mu_B^2}{k_B T_F} B$$