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Heavy Fermions

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A new approach is suggested to the whole area of issues related to the complex behaviour of the matter exhibiting highly-correlated electrons, as based on the assumption of a highly-fluctuating Fermi sea. Such fluctuations may originate in the interplay between high-mobility and low-mobility electrons, and may also be viewed as a competition between a wavevector description and a direct-space description. They range not only in magnitude, or energy scale, but also in spatial directions. All the same, the fluctuating electronic picture may be viewed as a statistical distribution of an ensemble with different Fermi seas. Similarly, it may be suggestive for the interaction between the f-quasi-localized electrons and the delocalized conduction electrons. It is expected to illustrate at least two features of such an approach, one related to a quantum phase transition driven by a controlling parameter (like magnetic field, pressure, doping, etc), and another related to introducing a second scale, a dynamical one, associated to the Fermi sea fluctuations, which would interplay with the scale temperature, the latter being known to affect seriously the quasi-particle behaviour.

Most of the standard Fermi liquid physics could hopefully be rewritten in terms of the Fluctuating Fermi Sea (FFS) model, including qausiparticle excitations, transport properties, phase transitions like superconductivity and magnetism, etc. Of particular importance in this respect might be the electron-lattice interactions, the fluctuating electronic states being presumably able to induce a similar behaviour in phonon states, leading to localized lattice vibrations, and coherent phonon states. Scaling laws associated with a fluctuating Fermi sea are typical for a quantum phase transition, and hopefully would provide, within such an approach, the power-laws behaviour of transport coefficients and response functions, (logarithmic corrections included).

Both the singular scattering theory of electron states near a quantum phase transition,[1] and the $f-d$ electron hybrization and composite nature of quasiparticles,[2] beside being rather strong assumptions, seem to imply a fluctuating Fermi sea, which makes the latter a promising new approach. On the other hand, it has, however, the status of a semi-phenomenological theory.

We illustrate this FFS approach by the renormalzied quasiparticle mass in theFErmi liqidtheory. As it is well-known, it is given by $1/m^* = 1/m - p_F F/\hbar^3$, where p_F is the Fermi momentum and F is a generic notation for the interacting parameter. It can be writen qualiattively as $F = vb^3$, where v is the strength of the interaction and b stands for its range. The dressed mass can also be written as

$$\frac{1}{m^*} = \frac{1 - mp_F F/\hbar^3}{m} \ . \tag{1}$$

The quasiparticles with dressed mass behave like free particles. If, however we change density (p_F) or increase the interaction, as in a FFS picture, the above formula must be reiterated. Obviously, the process ends only by assuming $m^* p_F F/\hbar^3 = const = C$ and vanishing interaction $F \rightarrow 0$. It follows that $C = 1$ and m^* becomes infinite. Therefore, the relationship $m^* p_F F/\hbar^3 = 1$ should hold good for heavy fermions. It can also be written as $\rho v b^3 = 1$, where ρ is the density of states (per energy and volume), or $f/a = 1$, where f is the scattering length and a denotes the mean inter-particle spacing

References

[1] A. J. Millis, Phys. Rev. **B48** 7183 (1993).

[2] Q. Si et al, Nature **413** 804 (2002).