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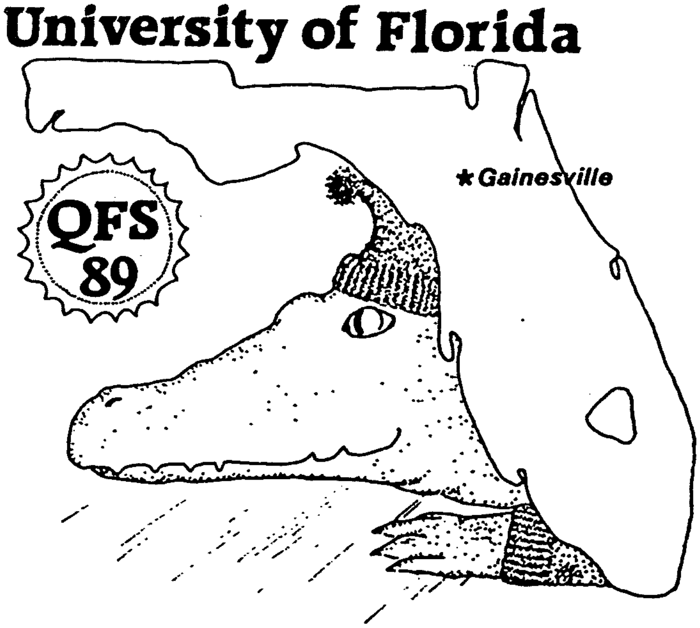

KINETIC PHENOMENA IN SPIN-POLARIZED QUANTUM SYSTEMS

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Abstract

I present a brief review of recent theoretical and experimental achievements concerning the kinetics of spin-polarized quantum systems. Recently serious attention has been paid to generalized and more accurate schemes of derivation of kinetic equations for such systems. Within different approaches the exchange and non-local effects, virial corrections and diagrammatic methods were studied in detail. The first calculations of transverse relaxation time responsible for attenuation of spin waves have also been performed. The new experimental results on transport phenomena are in reasonable agreement with theoretical predictions. The future studies of spin-polarized quantum systems are hampered by the lack of adequate and concise description of the particles' interaction with the walls such as boundary slip effects and magnetic relaxation. The latter is especially interesting and important at low temperatures because of possible magnetic ordering in the boundary ^{3}He layers.

1.Introduction

The considerable progress has been achieved recently in theoretical and experimental studies of spin-polarized quantum systems. Below I give a brief review of these new developments, and try to outline the remaining problems which seem to me to be the most intriguing. Some of the data are summarized in my reviews (Meyerovich, 1987; 1989a) and in the Proc.3-d Int. Conf. on Spin-Polarized Quantum Systems (Torino, Italy, July 1988).

Mostly I will consider kinetics of different ^{3}He$\uparrow$ systems though some of the ideas and results can be applied to the spin-polarized atomic hydrogen as well (the most important kinetic studies for H$\uparrow$ and D$\uparrow$ cover the depolarization and recombination processes and do not concern the polarization changes in transport and collective phenomena which I am mostly interested in). I will discuss both the longitudinal kinetics (transport) and transverse efffects (spin waves). What is more, now it is possible to discuss the kinetic peculiarities of spin-polarized systems in a more general context of kinetics in systems with arbitrary internal degrees of freedom. Some very recent results on kinetic equation for such systems provide one with more general understanding of the situation and show the interrelations between spin-polarized and other systems.

In the next Section I discuss new achievements in the general kinetic description of polarized systems. Then, in Sec.3, I proceed with more concrete recent theoretical and experimental results. In the concluding section (Sec.4) I list some unsettled problems which I believe to be rather important.

2.Spin-Polarized and Other Systems of Particles with Internal Degrees of Freedom

There is an important question. Is there anything very special about spin-polarized quantum systems that makes them different from systems of particles with other (non-spin) internal degrees of freedom? The general theory of such systems seems to be very well developed at least for dilute (gaseous) phases. Why not to substitute general commutation relations for operators corresponding to arbitrary internal degrees of freedom by commutation rules for spin operators and to introduce some asymmetry in the populations of internal states (the analog of spin polarization)? In principle, it is possible and must lead to complete and correct results. Especially this should be true for dilute (gaseous) systems for which there exists thoroughly studied general Boltzmann equation called for systems with the internal degrees of freedom the Waldmann-Snider equation (see, e.g., the review by Moraal, 1975). From this point of view the only peculiarity of systems in question is their extreme quantum nature as a result of rather low temperatures which makes various macroscopic quantum effects very pronounced and easily observable.

Fortunately, the studies of spin-polarized systems were performed independently. Otherwise we probably would not learn of the existence of the most exciting effects such as spin waves in Boltzmann gases and giant growth of transport coefficients with polarization.

The reason is that the existent Boltzmann equation for particles with internal degrees of freedom (e.g., molecules; the so-called Waldmann-Snider equation) does not include the effects of quantum identity of particles. Thus one should improve the Waldmann-Snider equation in order to describe the exchange effects properly.

Such a generalization has been recently performed (Meyerovich, 1989 b). The resulting kinetic equation is too cumbersome to be given here explicitly. I will only mention, that one gets some additional (exchange) terms in both the mean field and dissipative parts of the collision operator. The corrections to dissipative terms are not very important - within the standard Waldmann-Snider approach one can always take into account these corrections by proper symmetrization of scattering probabilities in the collision integral (it is not always easy, but at least possible). But I do not know any general procedures which one may use to obtain properly symmetrized mean field terms.

The resulting equation describes all the variety of kinetic phenomena (including quantum collective ones) in Boltzmann gases of particles with arbitrary internal degrees of freedom. If the only internal degrees of freedom are the spin ones (and the interaction is purely exchange and spin independent), then this equation reproduces all known effects in Boltzmann spin-polarized gases. But this equation is more general, and provides one with reliable approaches to some new phenomena.

Non-exchange effects. Usually the studies of spin-polarized quantum gases are performed within the exchange approximation neglecting all spin non-conserving interactions. Waiving of this assumtion permits one to study the influence of weak non-exchange (dipole) effects on properties of $^3He\uparrow$ (for polarized hydrogen these terms may describe the influence of slow recombination on kinetics). Small non-exchange terms being accounted for perturbatively provide one with the description of the frequency dispersion effects for longitudinal transport and relaxation processes. Moreover, without the exchange approximation there is no splitting of kinetic equation into independent longitudinal and transverse parts, and one can study the coupling between transport and spin-wave phenomena.

Collective coherent effects. The possibility of propagation of different (damped) collective modes in gases of particles with arbitrary internal degrees of freedom is ensured by the existence of strong molecular field with non-zero internal frequencies Ω which may be schematically written as

$$\Omega = \mathrm{Tr}\,\{\,\hat{P}\,\hat{T}\,[\hat{f}^{(0)},\ \delta\hat{f}]\,\}\,/\,\mathrm{Tr}\,\{\,\hat{P}\,\delta\hat{f}\,\}$$

where $\hat{T}$ is the scattering T-matrix, $\hat{f}^{(0)}$ is the equilibrium Wigner distribution function (which is a matrix in the space of internal variables), $\delta\hat{f}$ describes the deviation of the desired symmetry from equilibrium, $\hat{P}$ is the projection operator which characterizes the mode in question, and [...,...] is the commutator. The frequencies Ω are non-zero when (i) $\delta\hat{f}$ is non-diagonal in internal states and (ii) $\hat{f}^{(0)}$ is not a δ-matrix, i.e. there is some asymmetry in the equilibrium populations of internal states. With non-zero Ω there is a possibility of propagation of collective modes with quadratic spectrum, $\omega - \omega_0 \sim k^2T/m\Omega$, where T is the temperature, k is the corresponding wave vector, and m is the mass of particles. The situation becomes the most simple in the case of equidistant internal energy levels when

$$\omega = \omega_0 + (k^2T/m\Omega)(1 - i/\Omega\tau) / (1 + 1/\Omega^2\tau^2),$$

where ω_0 is the distance between the levels and τ is the usual collision relaxation time (certainly, a gas of two-level particles always corresponds to this case). Only in this case the situation is completely analogous to the spin waves in spin-polarized gases.

Non-local effects. Usually one assumes the locality of interaction taking into account only the lowest order (uniform) terms in the gradient expansion of the collision integral. One may waive this assumption and consider the non-local corrections to both coherent (mean field) and non-coherent (dissipative) interaction terms. The non-locality does not lead to any striking new effects, but it is very interesting and enlightening technically. The non-local effects for dilute polarized Boltzmann gases lead (Meyerovich, 1989b) to small corrections in density to the spin waves spectrum of the order of $\hbar\Omega/T$ (Ω is proportional to a density of a gas). These terms become important when one introduces the density (virial) corrections to the Boltzmann equation (Tastevin *et al*, 1988; Laloe, 1988). Moreover, the accurate study of non-local terms permits one to compare the classical kinetic (Lhuillier and Laloe, 1982) and Fermi-liquid (Bashkin and Meyerovich, 1979, 1981; Bashkin, 1981; Meyerovich, 1985) approaches to kinetic phenomena in polarized Boltzmann gases. The kinetic equations within these approaches differ by small non-local terms. The detailed analysis demonstrated that the corresponding high-order terms within both approaches are incomplete and should be modified. Farthermore, this analysis confirmed the earlier phenomenological prediction (Meyerovich, 1983) of the existence of important large non-local contributions for dense highly polarized systems such as liquid ^{3}He↑.

There appeared some other generalizations and improvements of kinetic equation. Laloe (1988) and Tastevin *et al* (1988) corrected the Waldmann-Snider equation making it possible to introduce virial corrections and to describe exactly the short-range two-body correlations. This was achieved by introducing, instead of usual Wigner transformation of density matrices, the so-called free Wigner transform which is somewhat analogous to interaction representation in the many-body theory. As a result, it became more easy to describe exactly the two-body collision. But the price was a considerable complification of kinetic equation governing the succession of two-particle collisions and describing the dynamics of corresponding distributions. Neverthless, it became possible to reproduce the Beth-Uhlenbeck (1937) second virial correction directly from the kinetic equation thus confirming the validity and the importance of the approach. Within this approach it is also possible to study the non-local terms, but the comparison with the more traditional approach outlined above is still rather difficult. Maybe it is worthwile to try to rewrite the final equation of Tastevin *et al* (1988) through the usual Wigner distributions and their derivatives (such a translation seems to be possible, but not very easy) in order to achieve better understanding of shortcomings of more conventional approaches.

There is another possibility of rigorous derivation of kinetic equation starting not from the master equation or BBKGY hierarchy, but exploiting one of the types of diagrammatic techniques such as, for example, Keldysh or Kadanoff-Baym formalisms. The latter approach has been used recently by Jeon and Mullin (1988) and by Ruckenstein and Levy (1989). But it is still early to make definite conclusions about possible advantages of such an approach, since the first publications only reproduced the already known results within this approach.

3.New Experimental and Theoretical Results on Transport in Spin-Polarized Systems

To an extent the situation with transport in spin-polarized bulk helium systems is now rather clear although there are only few experimental results.

In dense liquid ^{3}He there appeared first observations of change of viscosity with polarization (Kopietz *et al*, 1986; Vermeulen *et al*, 1988; Kranenburg *et al*, 1988). It is clear, that at not very high polarization $p=(N_+-N_-)/(N_++N_-)$ (N_+ and N_- are the densities of particles with up and down spins) the change in viscosity is quadratic in polarization,

$$\delta\eta/\eta = ap^2$$

Of course, at higher polarizations there should be deviations from this first term of the expansion in p. Usually in helium most of dimensionless parameters are of the order of unity. So when it turned out that, according to Kopietz *et al* (1986), the coefficient a is large and negative, $a \sim -25$, it was regarded as a sign of closeness to some possible phase transition (Bedell and Sanchez-Castro, 1986; Hess and Quader, 1987). But the later experiments gave more "normal" (and positive) values of a; $a \sim 2-4$ (Vermeulen *et al* 1988; Kranenburg *et al*, 1988). This last value seems to be more reliable since the experimental conditions corresponded to more equilibrium ones (especially in the case of Vermeulen *et al*,1988,when helium was polarized by the brute force technique).

The "normal" absolute value of the coefficient a makes it more difficult to present consistent quantitative theoretical description. The microscopic models do not have any definite accuracy, and all (except for those with some phase transitions) give reasonable values of a. Since up to now we do not have any consistent microscopic description of non-polarized ^{3}He, one can hardly expect reliable microscopic calculations of polarization effects.

On the other hand, the phenomenological calculations (Meyerovich, 1983; Anderson *et al*, 1987) are also not very helpful quantitatively - the phenomenological scattering probabilities of quasiparticles are unknown, and their polarization dependences cannot be extracted from the pressure dependences of transport coefficients of non-polarized ^{3}He. Qualitatively it is reasonable to believe that a should be positive and of the order of unity since the effective density of states increases and the main (s-wave) scattering channel becomes suppressed with polarization (Bashkin and Meyerovich, 1981).

The situation with dilute phases of $^3\mathrm{He}\uparrow$ ($^3\mathrm{He}\uparrow$ -^{4}He liquid mixtures and ^{3}He gas) is very different. The large growth of transport coefficients with polarization in such phases was reliably predicted long ago for both degenerate (Bashkin and Meyerovich, 1978) and non-degenerate (Meyerovich, 1978, 1982; Lhuillier and Laloe, 1982) cases, but except for qualitative observations of Greywall and Paalanen (1981) up to now there were no experimental results. The first quantitative experiment have appeared only recently for both ^{3}He gas (Leduc *et al*, 1987) and $^3\mathrm{He}\uparrow$ -^{4}He solutions (Bowley *et al*, 1988). In both experiments the observed increase of thermal conductivity and viscosity was in very good agreement with numerical calculations of Lhuillier (1983) for $^3\mathrm{He}\uparrow$ gas and of Hampson *et al* (1988) for $^3\mathrm{He}\uparrow$ -$^4\mathrm{He}$ liquid mixtures.

There are also several recent calculations of transport parameters for dilute polarized sytems. There appeared numerical calculations of transport coefficients for intermediate (between Boltzmann and degenerate) temperature region (Jeon and Mullin,1987; Hampson *et al*, 1988) in the s-wave scattering approximation. These variational results in the high-temperature limit coincide exactly with the first order Chapman-Enskog calculations of Lhuillier and Laloe (1982) and Meyerovich (1982), and in low-temperature limit - with variational results of Bashkin and Meyerovich (1978) and Meyerovich (1982). Such an exact fit of the results in both limits is not accidental and is due to the fact, that in all mentioned approximate approaches the trial functions were constants. In higher order approximations such exact correspondence would be rather unlikely: the Chapman-Enskog expansion and the exact solution of kinetic equation in degenerate case are based on trial functions of very different symmetries. These new calculations are applied to dilute $^3\mathrm{He}\uparrow$ -$^4\mathrm{He}$ solutions.

Another recent result concerns the calculation (Mullin and Miyake, 1986) of transport coefficients in semidegenerate $^3\mathrm{He}\uparrow$ - $^4\mathrm{He}$ liquid mixtures - systems (Meyerovich, 1978, 1985), in which due to the very high polarisation p, $N_+ >> N_-$, the spin-up component is dgenerate while the spin-down component is a Boltzmann one. Unfortunately, due to the difference in parametrizations it is rather difficult to compare the corresponding numerical results for viscosity with earlier calculations of Meyerovich (1978) for exactly the same case.

The most interesting is the situation with the so-called transverse relaxation time, $\tau_\perp$, and transverse spin diffusion coefficient, $D_\perp$, introduced by Meyerovich (1985) for exchange spin-polarized systems. The problem is very important (Meyerovich, 1985, 1987, 1989 a): though all usual continuous and spin echo NMR experiments study the relaxation and diffusion of transverse components of magnetization ($\tau_\perp$ and $D_\perp$), the standard spin diffusion calculations address only the diffusion of longitudinal component of magnetization (the diffusion coefficient D and the corresponding diffusion exchange relaxation time $\tau_{\parallel}$). Of course, at low polarizations the transverse and longitudinal coefficients are the same. Moreover, the calculations by Lhuillier and Laloe (1982) show, that there is practically no difference between these coefficients in the Boltzmann limit when the energies of particles do not depend on polarization. However, Meyerovich (1985) qualitatively demonstrated that in degenerate case $\tau_{\parallel} >> \tau_\perp$, and that the ratios $D_\perp / \tau_\perp$ and $D / \tau_{\parallel}$ being the universal functions of temperature coincide in high-temperature Boltzmann region and become more and more different with lowering temperature. It was shown, that the experimental results of Gully and Mullin (1984) on $\tau_\perp$ and $D_\perp$ are inconsistent with any calculations of $\tau_{\parallel}$ and D near and below degeneracy temperature, but, at the same time, these data on the ratio $\tau_\perp / D_\perp$ perfectly coincide with the theoretical temperature dependence of $\tau_\perp / D_\perp$ (Meyerovich, 1985) for all temperatures. Now the situation became more clear since there appeared direct kinetic calculations for $\tau_\perp$ by Jeon and Mullin (1988), McHale (1988), which confirmed the prediction $\tau_{\parallel} >> \tau_\perp$ (Meyerovich, 1985) for low temperatures. It is worth mentioning, that there are some plans (Nunes *et al*, 1988) of measuring for the first time the longitudinal diffusion coefficient D directly. If these attempts succeed, the picture will be complete.

It seems that nearly all possible analytical calculations for spin-polarized systems have already been done, and the remaining problems should be approached numerically or, at least, seminumerically. One of the few exceptions concerns the region where the chemical potential is nearly zero, and all the characteristics may be expanded in powers of this small chemical potential (Kumar, 1988).

The last problem I want to mention here is the problem of (spin) pressure diffusion. In usual hydrodynamic limit the flows (or currents) are proportional to the driving forces - gradients of macroscopic variables. In unpolarized (and one-component) systems there are two currents (mass and heat flows) and two driving forces. For spin-polarized sytems there is an additional flow (spin diffusion current) and an additional driving force - the gradient of polarization. Of course, the matrix of diffusion coefficients relating the currents to the driving forces contains not only the diagonal coefficients but also the off-diagonal ones. Thus the spin current contains the term proportional to the gradient of pressure P. This term corresponds to the pressure diffusion in ordinary binary mixtures, and in this context may be called the spin pressure diffusion current (Meyerovich, 1982, 1983). Usually the calculation of pressure diffusion is quite trivial since the diffusion current is proportional to the gradient of chemical potential, and the contribution to the (spin) diffusion current proportional to ∇P is equal to $D\,[(\partial\mu/\partial P)/(\partial\mu/\partial p)]\nabla P$. However, it is known (Zhdanov *et al*, 1962) that the calculations of pressure diffusion currents must include the terms proportional to the second spatial derivatives of mass velocity - due to the Navier-Stokes law these derivatives are of the same order as the first gradient of pressure in the stationary state. Therefore, the corresponding terms make the contribution to the (spin) pressure diffusion current of the same order as usual pressure diffusion terms thus leading to considerable "viscous" renormalization of pressure diffusion coefficient. Such calculations were performed by Ivanova and Meyerovich (1988) for different types of spin-polarized quantum systems. It turned out, that for all dilute binary (or polarized) systems the (spin) pressure diffusion ratio is equal to

$$k_{sp} = P\left[\frac{1}{m_+}\frac{\partial\mu_+}{\partial P} - \frac{1}{m_-}\frac{\partial\mu_-}{\partial P} - \frac{\eta_+}{m_+N_+\eta} + \frac{\eta_-}{m_-N_-\eta}\right] \Big/ \left[\frac{1}{m_+}\frac{\partial\mu_+}{\partial p} - \frac{1}{m_-}\frac{\partial\mu_-}{\partial p}\right]$$

where the indices + and - correspond to the components with up and down spins, m_+ and m_- are the (effective) masses of (quasi)particles, and η_+, η_- are the partial viscosities of (spin) components. The final expressions for k_{sp} through the particles' thermodynamic functions and cross-sections can be obtained from this equation in a rather straightforward manner. Note, that above the partial viscosities represent some sort of auxiliary quantities; they may be observed as real independent physical quantities only in high-frequency experiments studying, for example, the sound absorption in spin-polarized ^{3}He↑ systems.

Some progress has also been achieved in the study of spin waves in ^{3}He↑ systems. The most interesting development was the confirmation by Ishimoto *et al* (1987) of the existence of some definite ^{3}He concentration (between 3% and 5%) at which Ω being proportional to $F^{(a)}_0 - F^{(a)}_1/3$ is equal to zero ($F^{(a)}_i$ are the harmonics of the antisymmetric part of the Fermi liquid function). At lower concentrations of ^{3}He in ^{3}He-^{4}He solutions the internal frequency $\Omega > 0$, and at higher concentrations $\Omega < 0$. The presence of such a point could also be deduced from the previous observations by Owers-Bradley *et al* (1984) when Ω was negative at high ^{3}He concentrations (all the low concentration data lead to positive values of $F^{(a)}_0$ and

Ω). When Ω is equal to zero, the propagation of spin waves with quadratic spectrum becomes impossible (see Sec.2), and the spin wave spectrum obtains a very different structure (Bedell, 1989).

4. Remaining Problems

There are still many unsolved problems most of which concern dense phases such as liquid $^3\mathrm{He}\uparrow$and concentrated $^3\mathrm{He}\uparrow$-$^4\mathrm{He}$ solutions. But the real progress in this area is hindered not by some complicated peculiarities of polarized systems, but by the lack of comprehensive non-model many-body theory for dense quantum systems. On the other hand, the phenomenological approaches to these systems seem to be rather exhausted. Of course, since experimentally the field is not yet studied thoroughly enough, there is always a possibility of unexpected developments.

I would rather make comments on two other problems. The first concerns one of the most important current problems of ultralow temperature physics - the problem of superfluidity of ^{3}He in ^{3}He-^{4}He mixtures. At present it is the only one remaining system with considerable orbital entropy at ultralow temperatures. Therfore the solutions (along with other nuclear magnetic systems) inevitably will play more and more important role in future ultralow-temperature developments. The problem is to estimate reliably the superfluid transition temperature for ^{3}He in solutions. The existing estimates vary from much less than 10^{-3} mK up to about 1 mK. The reasons are very simple. Within all reasonable theories the pairing temperature is exponentially small in ^{3}He concentration. Even a very small uncertainity in the exponent leads to a large scatter (sometimes in orders of magnitude) for T_c. The scatter in the exponent is caused either by choice of different models or by uncertainity in interaction parameters. Note, that the reasonable description of transport and/or thermodynamic properties within some models does not mean that such models provide reasonable predictions for T_c. Below I illustrate this on the example of application of the usual BCS formula for solutions with 3% ^{3}He. In the Table I give the values of scattering length (extracted from different experimental data) and the corresponding values of T_c.

Data	*Scattering length, A*	*T_c, mK*
viscosity; Fisk and Hall,1972	- 0.75	0.03
thermal conductivity; Abel *et al*,1967	- 0.83	0.06
spin diffusion; Anderson *et al*, 1966	- 0.54	0.0015
Murdock *et al*, 1981	- 0.52	0.001
$\Omega\tau$ */D* ; Gully and Mullin,1984	- 0.5 --- - 0.7	0.0006 --- 0.02

What can be done to improve the accuracy? The problem for theory is to estimate the deviations from BCS formula at these concentrations, and the problem for experimentalists is to eliminate uncertainty in the interaction parameter (scattering length). From my point of view, the best way to achieve it is to perform more accurate spin echo experiments in highly polarized $^3\mathrm{He}\uparrow$-$^4\mathrm{He}$ mixtures - such an experiment provides one simultaneously with the data on $D_\perp$,$\Omega\tau_\perp$ and their ratio $D_\perp$

$/\Omega\tau_\perp$ which being the universal function of temperature (see above) gives the most accurate and model-independent data on scattering length. Up to now there were no signs of the superfuid transition in the ^{3}He subsystem down to the temperatures below 0.2 mK (the latest attempt has been made by Ishimoto *et al*, 1987).

There is an additional difficulty in observation of this superfluid transition. The superfluid transition with s-wave pairing may occur only if T_c is large enough in comparison with $\hbar/\tau^*$, where τ^* is the spin non-conserving collision relaxation time. The ^{3}He - ^{3}He magnetic nuclear dipole-dipole relaxation time is too long, and such processes are not dangerous. But at ultralow temperatures the (quasi)particles' mean free paths are very large, and the collisions with the walls become important. As a result, if T_c is of the order of several μK or lower, the collisions with the walls may prevent pairing. At such temperatures one should coat the walls by some non-magnetic materials (e.g., H_2) though such coating certainly does not improve the magnetic and temperature equilibration.

Unfortunately, there are no comprehensive theories and experimental data to obtain unambiguos values and low-temperature dependencies of τ^* for quasiparticles collisions with the walls. I feel that at present the absence of reasonable theory of magnetic relaxation at the walls is one of the major shortcomings. It hinders both theoretical and experimental progress in studies of polarized systems at ultralow temperatures. As a result, we practically do not understand the depolarization and some other processes, and cannot interpret and predict several important experiments. Of course, the wall relaxation strongly depends on the structure and the material of the wall, but still it is possible to understand some general features. Below I try to indicate some problems and outline some of the approaches.

Boundary slip. In most of experiments with spin-polarized systems one deals not with equilibrium, but stationary states of systems often in the presence of strong gradients (e.g., of temperature) and corresponding flows. In the presence of strong gradients the usual hydrodynamic boundary conditions (zero tangential velocity on the wall) are insufficient, and even small slip effects being multiplied by large gradients lead to considerable renormalization of system parameters. In this case one must use slip boundary conditions and to introduce a matrix of slip coefficients (in our case, 3x3; see, e.g., Ivanova and Meyerovich, 1988) relating three boundary currents (mass, heat and magnetic moment) to three driving forces - gradients of chemical potential, temperature, and tangential velocity. Standard stationary experimental situations correspond to zero mass flow, small known magnetization flow (slow depolarization), and known temperature gradient. Thus using the matrix of slip coefficients one can find the heat flow, and polarization and pressure gradients. At present the values of most slip coefficients are unknown. For calculations at low temperatures one may use the approach developed by Jensen *et al* (1980) and Onsager relations between off-diagonal coefficients derived by Ivanova and Meyerovich (1988).

Magnetic relaxation on the walls. This problem is crucial for ultralow temperature studies of polarized ^{3}He↑ systems. One cannot make any reliable predictions without information on the time of longitudinal spin relaxation on the walls. The problem is complicated by the presence of peculiar solidified and/or liquid helium boundary layers (in the presence of ^{4}He these layers consist mostly of ^{4}He, but even a small admixture of ^{3}He in the boundary layers has a very large influence on the wall relaxation). Therefore the magnetic relaxation on the walls is a two-step process - exchange interaction of ^{3}He from the bulk with ^{3}He particles in the boundary layers, and the interaction of ^{3}He boundary particles with magnetic subsystem of substrate.

The latter processes depend on the stucture of the wall and may correspond to magnetic dipole interaction with conduction electrons (metals) and paramagnetic atoms, or to exchange interaction with some nuclei (e.g., ^{19}F). These processes may be also affected by possible diffusion of ^{3}He into the wall. As a result, this step in depolarization differs from case to case.

The depolarization of bulk $^{3}\mathrm{He}\uparrow$ via the exchange interaction with helium particles in the boundary layers is a more general and strongly temperature dependent process. One of the origins of such dependence is the T^{-2} dependence of mean free paths and spin diffusion coefficients in normal dense $^{3}\mathrm{He}\uparrow$ or $^{3}\mathrm{He}\uparrow$-^{4}He; in superfluid ^{3}He this factor may be masked by superfluid spin currents. Another temperature dependent factor is the (quasi)particle cross-section by the wall in the channel with the change of spin state. This cross-section is analogous to that of depolarization cross-section for polarized neutrons by heavy nuclei, and depends on the structure of localized ^{3}He levels near the wall. If there are resonance or quasi-resonance levels near the Fermi energy, then depolarization goes through the formation of long-lived quasi-bound state (analog of compound nuclei), and the depolarization probability in the scattering act is nearly 1/2. On the other hand, if there are no qasi-bound states near the Fermi energy, then the depolarization probability is much smaller, especially for ^{3}He-^{4}He solutions where the probability of a purely specular elastic reflection is practically equal to 1 due to the properties of one-dimensional scattering of low energy particles.

The situation becomes very different below the temperature of a possible magnetic phase transition in ^{3}He boundary layers. This transition may take place for many different substrates, and below this transition ^{3}He is probably ferromagnetic. Below the transition the depolarization rate will begin to decrease exponentially as $exp(-J/T)$ (J is the characteristic magnetic interaction energy in the boundary layers) down to the the temperatures about $T \sim \hbar J^{1/2}/l\, m^{1/2}$ when this exponetial factor reaches the value $exp[-l\,(mJ)^{1/2}/\hbar\,]$ corresponding to tunneling of inverse spin through the ferromagnetically ordered boundary layer of the thickness l. In this case the depolarization process is somewhat analogous to that considered for magnetically ordered ^{3}He liquid-solid interface (Meyerovich and Spivak, 1981).

Summarizing, I want to emphasize, that the wall depolarization is characterized by several unknown parameters, and our real understanding of the situation will improve only after systematic experiments on depolarization time.

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