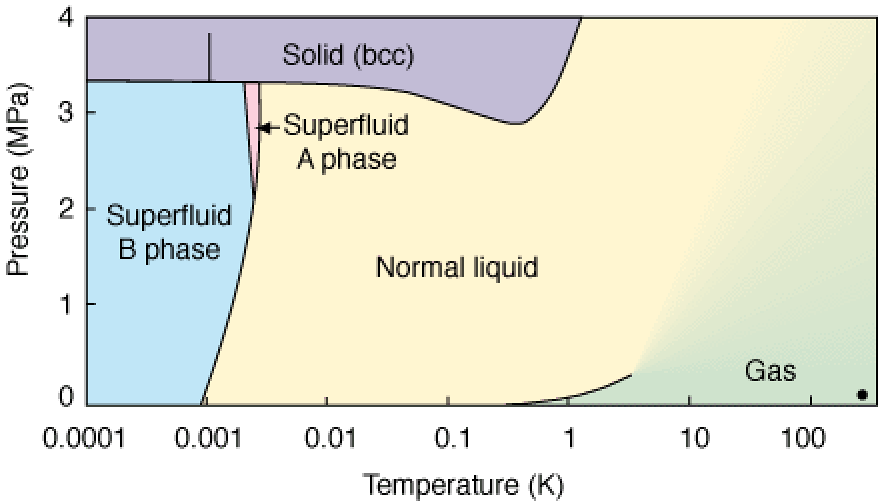
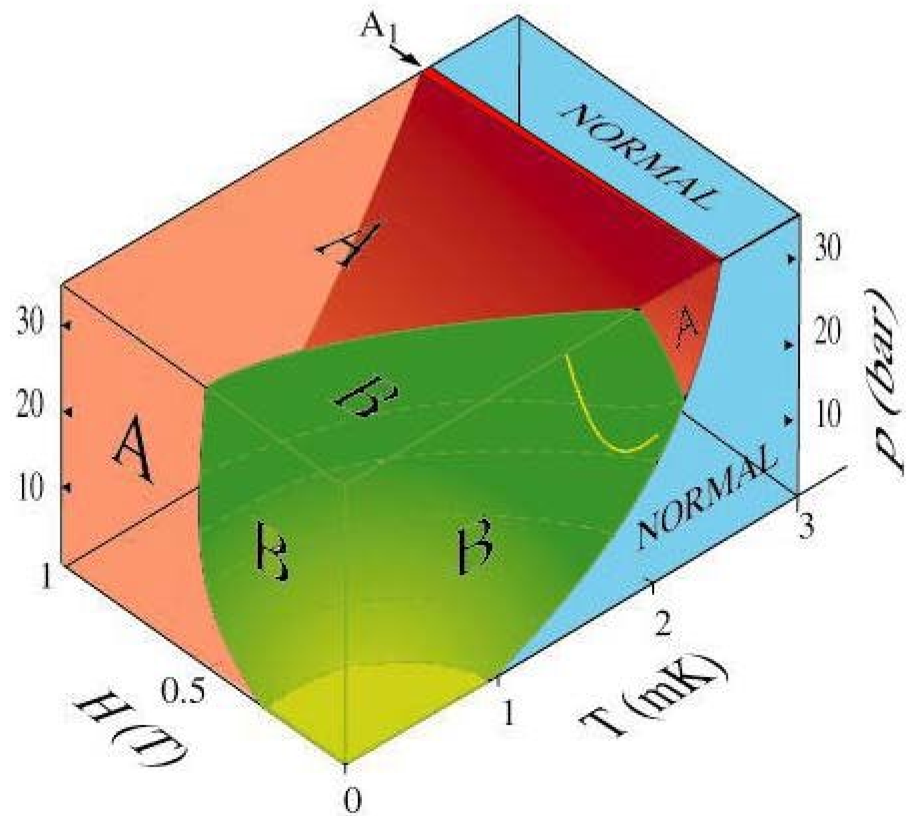
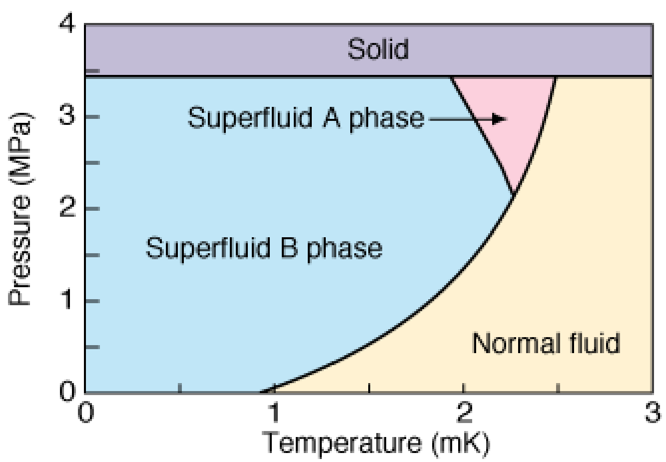
Superfluid ^3He







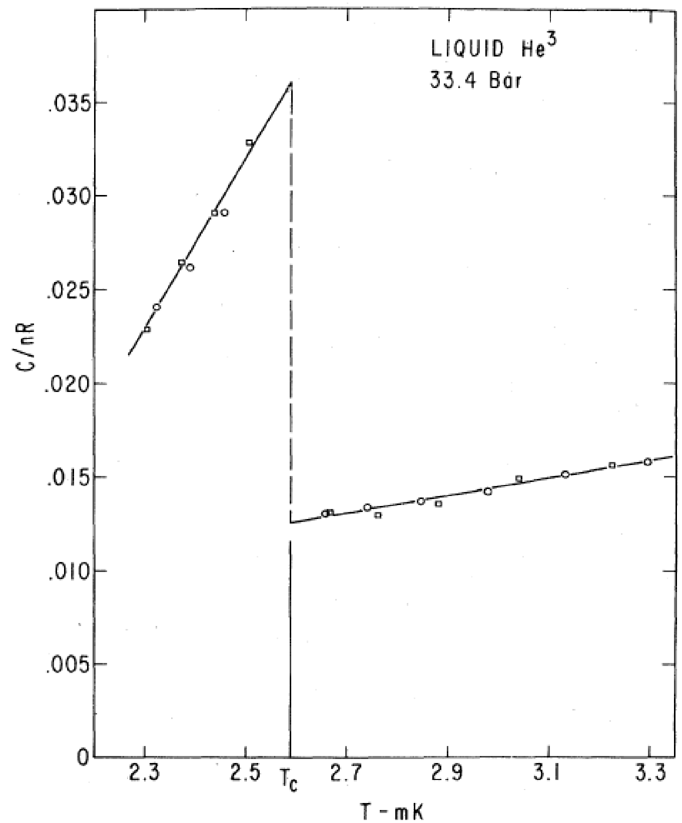
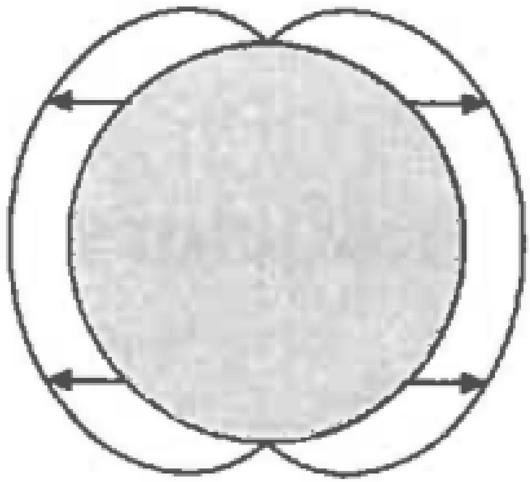


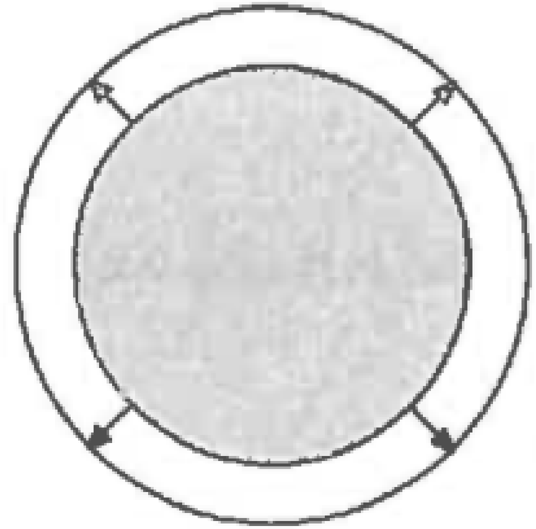
FIG. 5. Molar specific heat relative to the gas constant R for liquid ^{3}He at 33.4 bar near the second-order transition. (After Webb, Greytak, Johnson, and Wheatley, 1973b).

John C. Wheatley, "Experimental properties of superfluid ^{3}He," Rev Mod Phys **47 (2), 415-470 (1975).**

^{3}He-A



^{3}He-B



$$\vec{d}(\vec{k}) = \left(\sqrt{\frac{3}{4\pi}}\,\sin\theta_{\vec{k}}\,(\cos\varphi_{\vec{k}} + \sin\varphi_{\vec{k}}), 0, 0\right)$$

$$\left|\vec{d}(\vec{k})\right| \sim \sin\theta_{\vec{k}}$$

Made up of $|\uparrow\uparrow\rangle$ and $|\downarrow\downarrow\rangle$, $S = 1$, $S_z = \pm 1$ states

$$\vec{d}(\vec{k}) = \sqrt{\frac{3}{4\pi}}\left(\sin\theta_{\vec{k}}\,\cos\varphi_{\vec{k}}, \sin\theta_{\vec{k}}\,\sin\varphi_{\vec{k}}, \cos\theta_{\vec{k}}\right)$$

$$\left|\vec{d}(\vec{k})\right| \sim constant$$

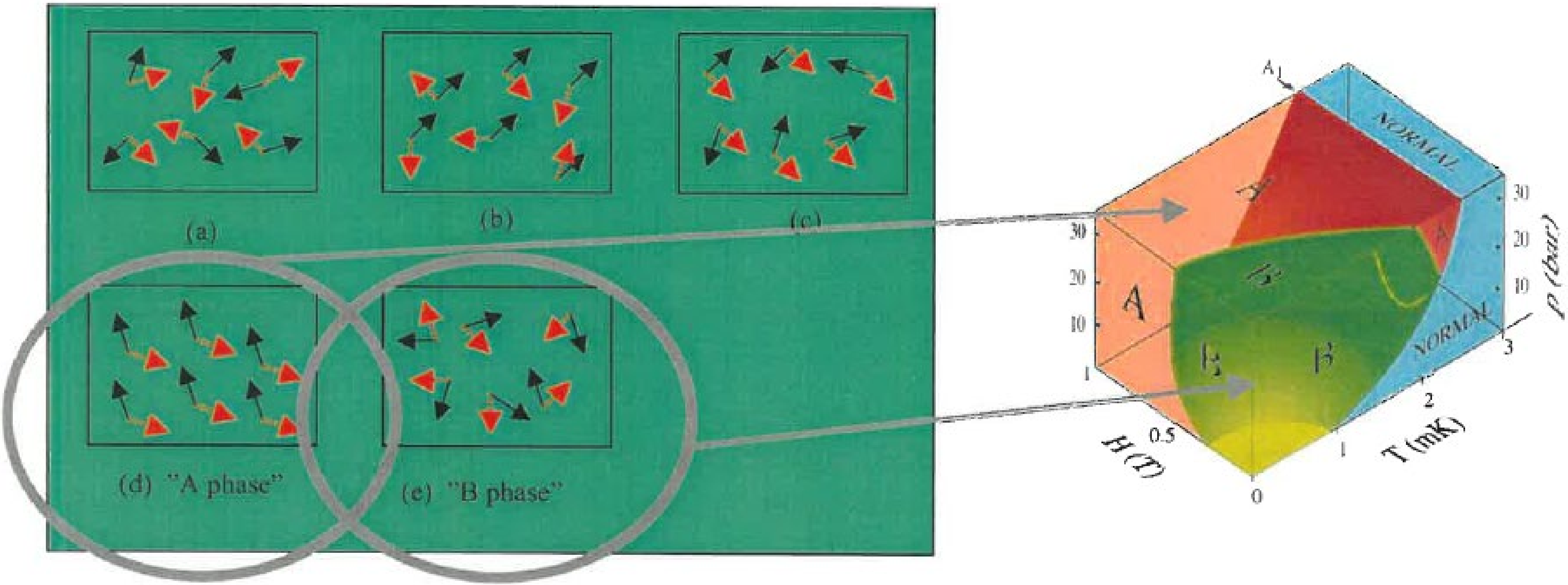
Made up of $\frac{|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle}{\sqrt{2}}$, $S = 1$, $S_z = 0$ state

Fig. 7.4 The main two superfluid phases of ^{3}He. The A phase has a **d** vector in a constant direction and has two gap nodes at the "north" and "south" poles of the spherical Fermi surface. The B phase has a constant magnitude **d** vector everywhere on the Fermi surface, and hence a constant gap value.

Parity symmetry property: $\vec{d}(\vec{k}) = -\vec{d}(-\vec{k})$

James F. Annett, *Superconductivity, Superfluids and Condensates* (Oxford, 2004)

Possible situations of different broken symmetries



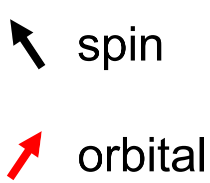
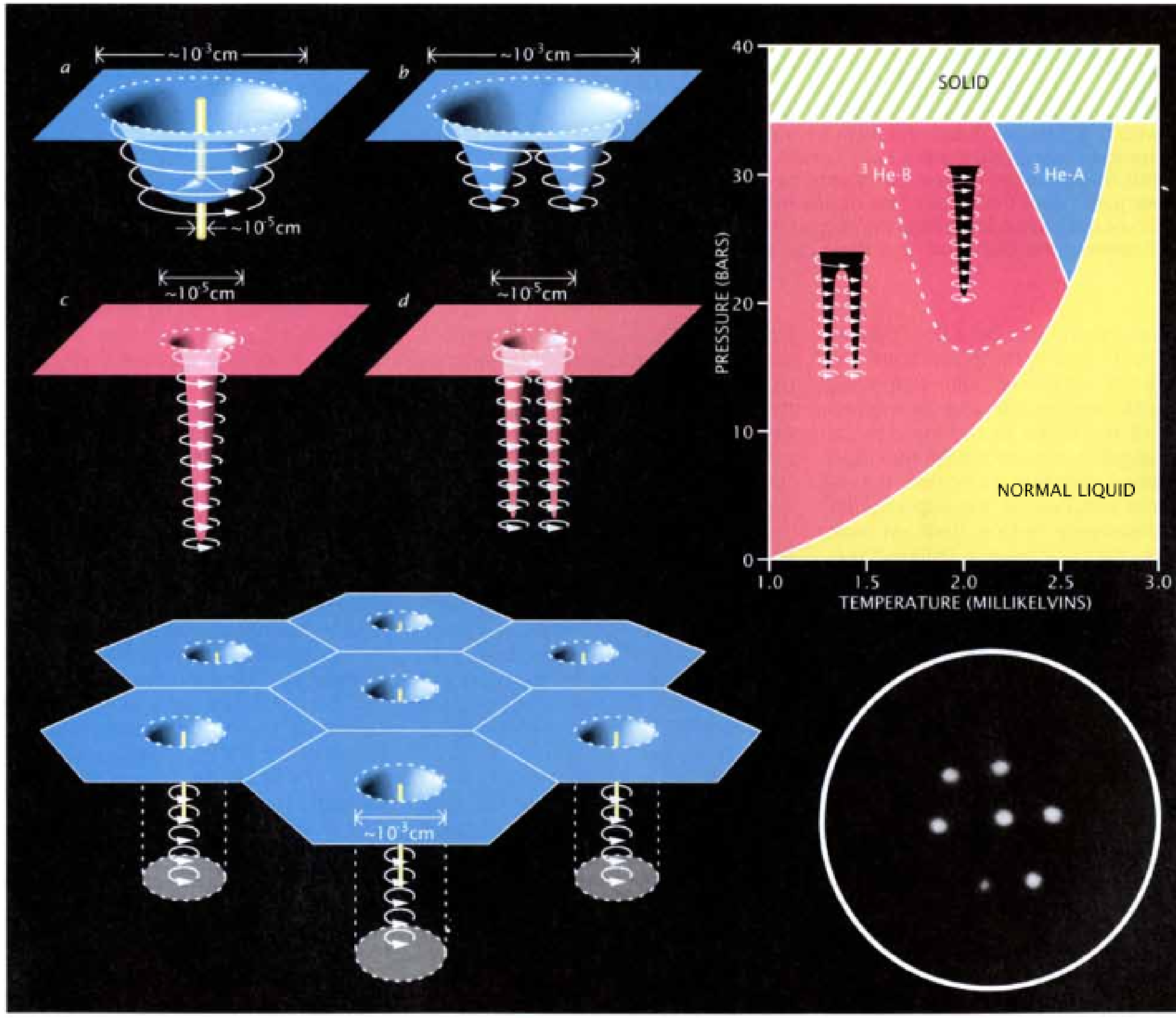


Figure 1. The possible states in a two-dimensional model liquid of particles with two internal degrees of freedom: spin (full-line arrow) and orbital angular momentum (broken-line arrow). (a) Disordered state: isotropic with respect to the orientation of both degrees of freedom. The system is invariant under separate rotations in spin and orbital space and has no long range order (paramagnetic liquid). (b)–(e) States with different types of long range order corresponding to all possible broken symmetries. (b) Broken rotational symmetry in spin space (ferromagnetic liquid). (c) Broken rotational symmetry in orbital space ("liquid crystal"). (d) Rotational symmetries in both spin and orbital space *separately* broken (as in the A phase of superfluid ^{3}He). (e) Only the symmetry related to the *relative* orientation of the spin and orbital degrees of freedom is broken (as in the B phase of superfluid ^{3}He). Leggett introduced the term spontaneosuly broken spin-orbit symmetry for the broken symmetry leading to the ordered states in (d) and (e).

Vortices in superfluid ^{3}He.
Single-core and double-core vortices



UNIQUE PROPERTIES of superfluid ^{3}He include the formation of at least four different kinds of vortices as the fluid is rotated. The quantum-mechanical properties of the liquid prevent it from rotating as a whole in the way that normal fluids do. A phase diagram (*upper right*) shows the conditions under which vortices form. ^{3}He-A can sustain vortices with either single cores (*a*) or double cores (*b*). The type of vortex that forms depends on the cooling history of the sample. The single-cored vortex is discontinuous: a minuscule thread of ordinary fluid runs through its center. The B phase also supports single-cored (*c*) and double-cored (*d*) vortices. The diameters of the ^{3}He-B vortices are much smaller than they are in the A phase, and both B-phase vortices are discontinuous. The fluid flows that make up individual vortices tend to repel each other, so that the vortices arrange themselves in a stable hexagonal lattice (*bottom*). Richard E. Packard of the University of California at Berkeley has photographed such a lattice in ^{4}He, which supports only one type of vortex (*lower right*).

The ^{3}He Superfluids
Author(s): Olli V. Lounasmaa and George Pickett
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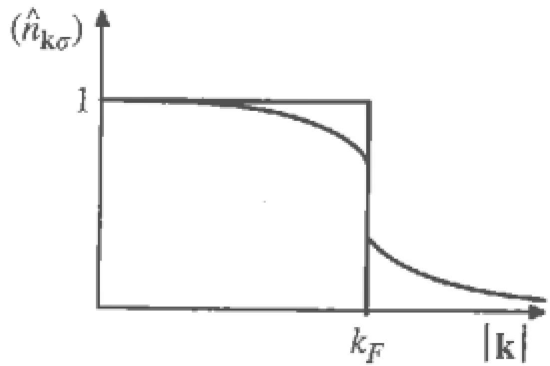

Fig. 7.2 Momentum distribution of the ideal (noninteracting) Fermi gas, and an interacting Fermi liquid. The discontinuity at k_F remains, although the height of the discontinuity is reduced from 1 to a smaller number, Z.

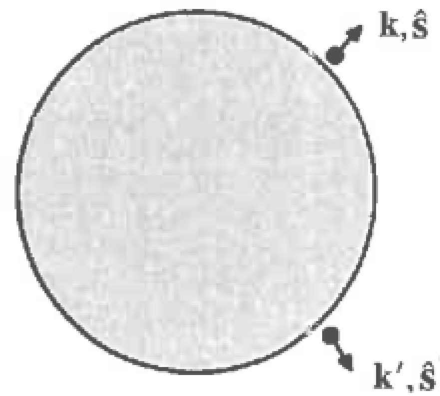

Fig. 7.3 Interactions between quasiparticles near the Fermi surface in Landau Fermi liquid. The interaction depends on two contributions: one which does not depend on the relative spin orientations $\hat{\mathbf{s}}$, $\hat{\mathbf{s}}'$, and one which does. Both interactions are functions of $\mathbf{k}$ and $\mathbf{k}'$.

James F. Annett, *Superconductivity, Superfluids and Condensates* (Oxford, 2004)