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What we know and have yet to learn about spinor Bose-Einstein condensates[1]

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The fundamental properties of a spinor Bose-Einstein condensate (BEC) are determined by both spin-exchange and dipole interactions. The spin-dependent part of the interaction (spin-exchange interaction) is three orders of magnitude smaller than the spin-independent one and usually much smaller than the temperature of the system. Yet, due to bosonic stimulation, it profoundly affects the properties of the system. The magnitude of the local spin is primarily determined by the sign of the spin-exchange interaction. The magnetic dipole-dipole interaction is even smaller in magnitude than the spin-exchange interaction; however, it plays a crucial role in forming the spin texture, which is the spatial distribution of the spin orientation, and controls the long-term dynamics of magnetization. Spinor condensates can exhibit various topological excitations such as fractional vortices and non-abelian excitations. However, the structure of the singular core has remained unclear, because the internal degrees of freedom allow various possible states to fill in the core. Dynamical instabilities, which will ensue when we start from the "wrong" ground state, can yield a rich variety of excitations and will be an ideal testing ground for the Kibble mechanism. By suddenly altering the strength of the interaction, we can induce a second-order quantum phase transition from one phase to another. The ensuing dynamics follow two stages, which have different time scales. The first stage involves formation of spin domains, each domain having an independent phase coherence. This domain formation is driven by dynamical instabilities, and the final pattern is very sensitive to the initial seeds, of both thermal and quantum origins. The second stage involves generating topological defects that reconcile phase relations independently established among different domains. In this second stage, we might also envisage two-body spin correlations being caused by the dipolar interaction. The many-body nature of the spinor condensate remains a big challenge. In the single-mode approximation, where we ignore the spatial dependence of the spin, we have a complete understanding of the spin-1 BEC, and a good knowledge of the spin-2 BEC. However, the single-mode approximation is likely to be violated by the dipole interaction, and fragmented BECs are highly vulnerable to symmetry-breaking perturbations. It is conceivable that an exotic pair, trio, quartet, or even sextet state could emerge in high-spin systems, but the real question is which state is viable and under what conditions. I will attempt to provide an overview of what we know and what we have yet to learn about spinor BECs.

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