Chapter 1

Introductory Chapter

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1. Generalities on superfluidity and superconductivity

This book deals with the recent advancements in two topical subjects of condensed matter physics, superfluidity, and superconductivity. In principle, the two phenomena are very similar because they occur as a function of temperature and in the presence of the vanishing of a physical quantity marking a phase transition below a critical temperature. A superfluid is a fluid having zero viscosity while a superconductor is a conductor with zero resistance. Superfluidity occurs in liquid helium and in ultracold atomic gases while superconductivity is typical of elements like niobium and lead, of some niobium alloys, or compounds like yttrium barium and copper oxide and compounds containing iron. Regarding the latter, since the first discoveries, the interplay between superconductivity and magnetism has also been investigated finding that the magnetic state of superconductors can be described as ideal diamagnetism. The behaviour toward the external magnetic field allows to distinguish between first- and second-type superconductors. Instead, the critical temperature in correspondence of which superconductivity arises allows to distinguish between low- and high-critical temperature superconductors. After their initial discovery, superfluidity was explained as a quantum mechanical phenomenon, while superconductivity was described first according to a phenomenological and classical theory and only in a second moment in terms of a microscopic quantum mechanical theory.

2. Topological properties of superfluids and superconductors

Recently, there has been a growing interest in both fields for the important implications of the two phenomena in terms of their topological properties. In particular, if stirred, superfluids form cellular vortices that rotate indefinitely. On the other hand, also multiply-connected superconductors form vortices giving rise to flux quantization that can be just like the quantization of circulation in multiply-connected superfluids. Quantized vortex structures are characterized by a singularity in the center and the vortex core is quantified by means of vorticity, a topological charge otherwise called winding number characterizing the strength of a vortex and identifying superfluid and superconducting vortices as topological defects. This description is an important step forward in both fields because the study of the topological properties is crucial to fully understand the underlying physics in the systems exhibiting either superconductivity or superfluidity.

3. Contents and organization of the book

In the next six chapters of the book, some of the recent novelties in the two fields of superconductivity and superfluidity are reviewed both from a theoretical and an experimental point of view. The book is organized into two sections: (1) the first section contains three chapters dealing with the recent developed theoretical models and measurements carried out in superconductors and (2) the last three chapters contained in the second section report on the theoretical advancement together with the most sophisticated experimental techniques in superfluidity. In more detail, Chapter 2 reviews the main properties of the intermediate state in type-I superconductors and the main theoretical models to interpret it. Chapter 3 reports the recent experiments on some emerging superconductors, the bismuth chalcogenides, and the BiS_2-based layered superconductors with special regard to the correlation between crystal structure and superconductivity. Chapter 4 reports on the effect of isovalent substitutions and heat treatments on some physical properties of high-critical temperature superconductors by means of advanced experimental techniques. Chapter 5 presents an advanced theory in the field of superfluids on the Kelvin wave and knot dynamics on three-dimensional deformed knot-crystal and its relation with deformed space-time. Chapter 6 outlines an effective field theory applied to study vortices and solitons in superfluid Fermi gases. Chapter 7 describes an experimental technique that is able to produce hydrogen-free liquid helium and illustrates how to solve the flow impedance blocking issue.

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