Modern Quantum Physics of Solids

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Introduction

The concepts and models that are widely used in the study of the properties of condensed matter will be discussed along with experimental results. These concepts and models are developed in order to interpret and explain the results of various experiments.

The condensed matter physics is in many ways an eclectic discipline. We will use our knowledge of the basics of quantum mechanics, thermodynamics and statistical physics, theory of elasticity and electrodynamics of continuous media. The style of these lectures will therefore differ from courses in introductory physics.

Models in physics are developed in a way that allows describing a physical phenomenon with a minimal set of assumptions. The same is true for models and concepts that are developed to understand the properties of condensed matter.

We will mostly discuss simplified models of solids, which in most cases describe the properties of real solids only approximately.

In spite of such simplifications, it is often possible to provide a fairly good description of the properties of solids, at least qualitatively.

As a rule, solids comprise a large number of atoms.

We therefore will have to learn how to adequately describe systems that contain many particles and have many degrees of freedom.

Experimental solid-state physics often studies the response of solids to external parameters such as hydrostatic or uniaxial pressure, temperature, electrical or magnetic field.

The methods of investigation can be either macroscopic or microscopic.

New and unexpected experimental results often lead to a development of new theoretical models. On the other hand, so-called model solids are investigated under certain conditions in order to make a comparison with theoretical models possible.

We expect that the students will better understand these interrelations between experiment and theory, which often lead to progress in physics.

This lecture course should be considered as a minimum necessary for physics students. Its purpose is to facilitate the study of textbooks and more advanced lecture courses.

Textbooks

Charles Kittel, Introduction to Solid State Physics.

Neil W. Ashcroft and N. David Mermin, *Solid State Physics*.

Michael P. Marder, *Condensed Matter Physics*.

Problems and solutions

László Mihály and Michael C. Martin, *Solid State Physics: Problems and Solutions.*

Eugene M. Chudnovsky, Javier Tejada, Carlos Calero, Ferran Macia, *Problem Solutions to Lectures on Magnetism.*

Additional textbooks

P. M. Chaikin and T. C. Lubensky, *Principles of Condensed Matter Physics.*

Leonard M. Sander, *Advanced Condensed Matter Physics.*

Stephen Blundell, *Magnetism in Condensed Matter.*

Eugene M. Chudnovsky, Javier Tejada, *Lectures on Magnetism (with 128 problems).*

Marius Grundmann, *The Physics of Semiconductors: An Introduction Including Devices and Nanophysics.*

Harald Ibach and Hans Lüth, *Solid-State Physics: An Introduction to Theory and Experiment*.

C. Janot, *Quasicrystals: A Primer.*

Types of solids

- Periodically ordered crystals,
- Amorphous solids
- Other types of solids

Two extreme forms of condensed matter: liquids and periodically ordered crystals.

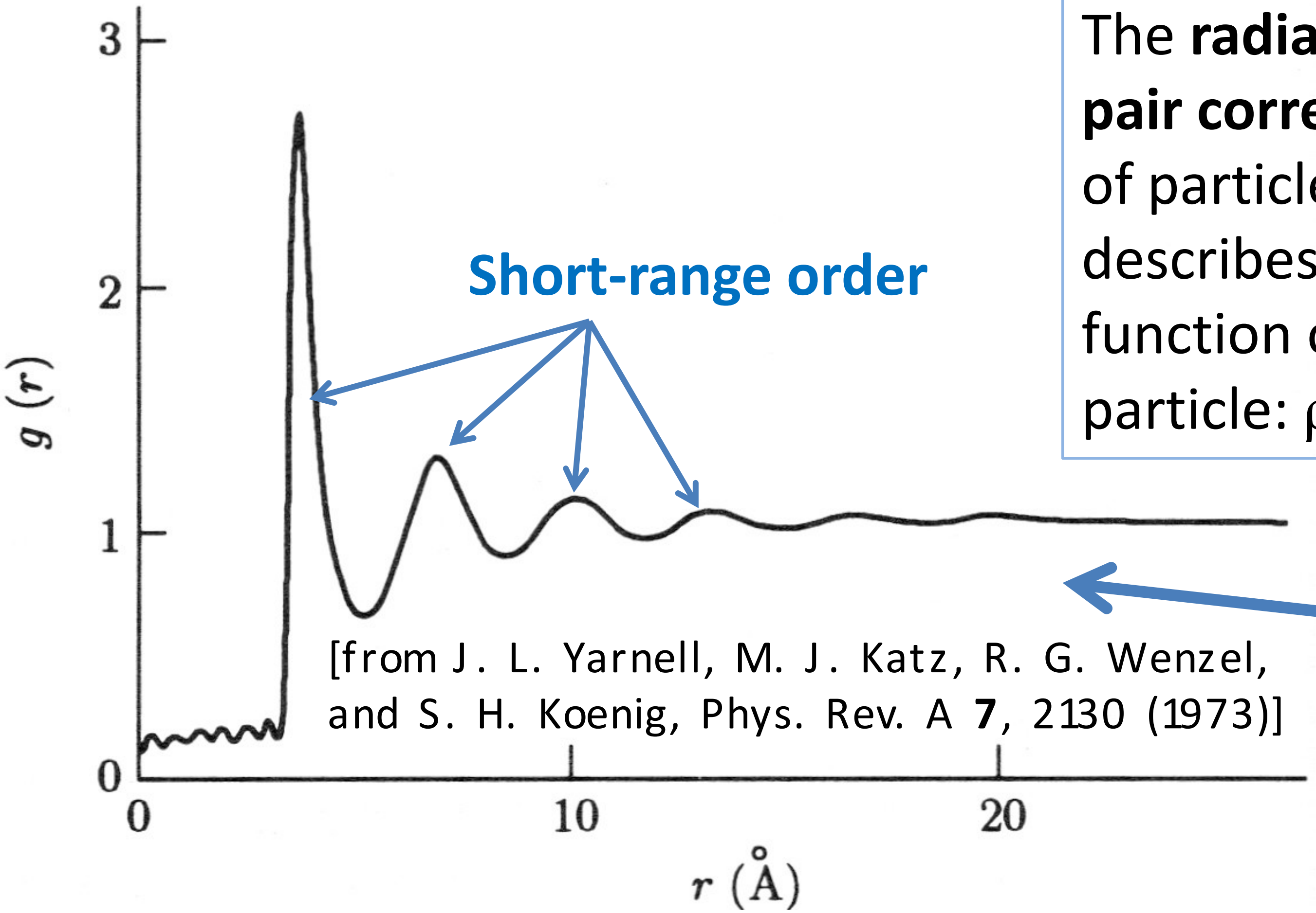
Liquids: short range order and no long-range order.

Crystals: long-range positional and rotational order.

Liquids vs. crystals – symmetry

The most ordered type of condensed matter is a periodic crystal with long-range atomic order of certain symmetry.

Difference between the radial distribution function g(r) in crystals, liquids and gases

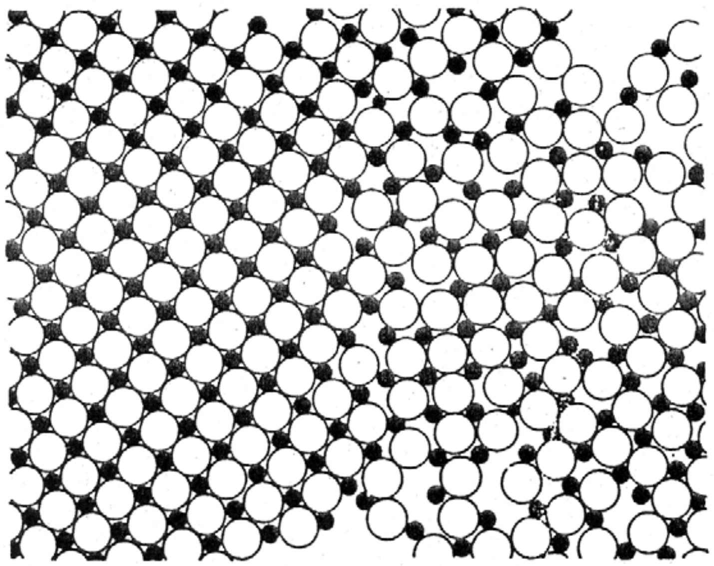


The **radial distribution function** g(r) (or **pair correlation function**) in a system of particles (atoms, molecules, etc.), describes how density varies as a function of distance from a reference particle: $\rho(r)=\rho_0 g(r)$.

Liquids: the radial distribution function g(r) for liquid argon at 85 K obtained from the neutron-diffraction data.

In gases there is no short range order. In liquids there is short-range order. In crystals there is long-range order.

The difference between a crystal and a liquid schematically shown for a two-dimensional case:



[from H. R. Ott, Festkörperphysik I, 1995]

Intermediate order: there are systems that exhibit types of order, which are intermediate between the perfect order and complete disorder.