THEORY OF ELECTRONIC TRANSPORT
IN TWO-DIMENSIONAL SYSTEMS IN THE PRESENCE OF MAGNETIC FIELDS

I. The Landauer formalism

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The series of three papers is focused on the Landauer-Büttiker approach to the study of transport in two-dimensional electron systems, with particular attention paid to the influence of an external magnetic field. In the present paper, various aspects of the Landauer formalism (relating conductances to transmission coefficients) are reviewed. The one-dimensional case is discussed in detail. Some views on its generalization to higher dimensionality are presented. The connection to the linear response theory is briefly discussed. A short account of the Büttiker formalism for systems with more than two probes is given. Further the Landauer formalism is generalized for two-dimensional systems in quantizing magnetic fields. Particular attention is paid to the role of ideal leads where edge states occur.

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1. Introduction to the series

Recently, the Landauer-Büttiker approach has become a very efficient and simple tool for describing the transport properties in solid state physics. The essence of the formalism consists in expressing the transport properties in terms of the transmission and reflection coefficients, associated with the quantum-mechanical scattering matrices of the systems considered. The main aim of the present series of three papers is to explain various aspects of the formalism, with particular emphasis put on its application to semiconductor systems containing two-dimensional electron gas, subject to external magnetic field.

The series is organized as follows. In the present paper [I] we review the Landauer formalism and elucidate its generalization to the Hall-bar samples in the quantum-Hall-effect regime. In the next paper [II], we demonstrate how the Landauer formalism may be verified by means of linear response theory. Finally, to provide comparison with experimental results, we apply the formalism to a quasiclassical calculation of the magnetoresistance of gated samples, in the last paper of the series [III].

Throughout the series, emphasis is put on the clarity and lucidity of the explanation.

2. Overview

2.1. Historical introduction

More than 30 years have passed since R. Landauer published his pioneering work [1] on the electronic transport theory. Although the concept originally suffered from lack of interest or even retentivity from a part of physicists [2], it has eventually received its rewarding attention.

In [1] Landauer pointed out the fact that electronic transport in solid state may be conceived as a scattering problem. He then attempted to find a relation between the conductivity of the system and its scattering characteristics. At first, let us describe the simplest configuration commonly used in resistance measurement. The sample under investigation is connected to a battery with good metallic leads; both the current through the leads and the voltage difference between them are measured. The battery represents a mighty source of conducting particles; its strength is characterized by its internal resistance. Under the assumption that the sample resistivity is much greater, the battery may be considered as a 'hard source', i.e., its behaviour is not influenced by the measurement process. Simultaneously, the conductivity of materials used for leads is generally good. Now, let us compare the above description with the model, proposed by Landauer in the simplest, one-dimensional case [3]. We start from the configuration of the tunnel phenomenon, currently described in textbooks on quantum mechanics (see e.g. [4] and Fig. 2.1). The potential barrier forms the 'scatterer', i.e., an obstacle for propagating electrons. On both sides of the barrier the region of constant potential constitutes the ideal leads (of arbitrary