1 Introduction: Electron and Photon Systems

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While previous books about nanometer scale phenomena have dealt with either electronic states or electromagnetic fields, this book is concerned with both as a unified whole. The characteristics of electrons or electromagnetic fields apparent at nanometer scales are quite different from those at the macroscopic scale. Nowadays these areas are called nanoscience or nanotechnology. They attract the interest of a wide range of people for their applications to new branches of technology [1–15].

When we deal with electromagnetic fields at the nanometer scale, the scale of interest is much shorter than the wavelength of light, at approximately 1 μm. The characteristics of such electromagnetic fields are therefore quite different from those pertaining to macroscopic sizes. The former are characterized as localized waves, while the latter are characterized as propagating waves. The former nanoscale wave is usually called an evanescent wave and its characteristics have now been studied by many researchers [16–50].

For electron waves, the situation is similar to that of a propagating light wave in that an electron can propagate through crystalline metals and semiconductors, whereas on nanoscales, when a metal block is cut in half, the propagating electron wave starts to penetrate into the vacuum from the surface. The nature of this penetrating wave can be very similar to that of an evanescent light wave. The electron wave penetrating the vacuum appears as a tunneling phenomenon: the electron can pass through a potential barrier. These features have been studied using the scanning tunneling microscope (STM) [51].

Consider the relationship between an electron and an electromagnetic field. Electromagnetism shows that the moving charged particle causes an energy flow, called a Poynting vector. Thus the field of the electron and the electromagnetic field are closely related. This interaction has been well studied at the macroscopic scale but not at the nanoscale.

One can see the interaction of an electron and the electromagnetic field in the case of a Coulomb blockade [52–62]. A Coulomb blockade can be described as follows. A double tunnel junction is biased by a battery. When the battery does work and the Fermi level of the emitter reaches the chemical potential of the central electrode of the double tunnel junction, electrons can tunnel through the first tunnel barrier by overcoming the Coulomb energy $e^2C/2$, where $C$ is the macroscopic capacitance of the tunnel junction. When an electron tunnels through the potential barrier, the Poynting vector crosses
a resistor that is connected to the double tunnel junction, indicating that current flows through the junction.

While the interaction between electrons and electromagnetic fields is a most interesting phenomenon, it has not yet been studied properly at the nanometer scale. The reason for this can be entirely attributed to the lack of technological development both in realizing nanometer scale structures and also in connecting them to excitation sources and detectors. For example, the interaction between a penetrating electron wave, i.e., a tunneling electron, and an electromagnetic field has been studied. A planar tunnel junction was prepared and then irradiated by light. Since a tunneling current was detected, the existence of a penetrating or decaying electron wave was deduced. However, as both the electrode and the tunnel barrier were irradiated, it was not possible to extract the net interaction effect between the tunneling electron and the evanescent field from the interaction between the propagating electron wave and the electromagnetic field in the electrodes. Due to the experimental set up, the details of the interaction were not revealed.

A similar situation occurred in an experiment involving the interaction between a propagating electron and an evanescent field, although in this case not involving a tunneling electron (Chap. 5). Light was introduced into an insulating slab through which the propagating electron flowed. Since the nature of the electromagnetic field in an insulator is evanescent, the propagating electron was assumed to interact with the evanescent wave in the slab. Light emission was observed after the electron reached a non-fluorescent screen. This is thought to be a consequence of the interaction between the propagating electron and the evanescent field. However, as the propagating electron interacts with the material of the slab itself, one cannot distinguish the interaction of the electron and the evanescent field from the interaction between the electron and the matter.

These examples show that it is no trivial task to set up an experiment that distinguishes the interaction between a tunneling electron and an evanescent field from the other possibilities. In this book, the reader will discover some efforts in this direction. Owing to the recent development of nanoscience and nanotechnology, we now possess a variety of tools for realizing experimental setups that can probe the interaction between a tunneling electron and an evanescent field.

The purpose of this book is to show the importance of constructing nanoscale electric and electromagnetic fields connected to a reservoir. We start with a conventional electric or electromagnetic field treatment, for which many theoretical and experimental results have been accumulated, and then move on to the importance of the reservoir connection.