

2 Basic Concepts of Entangled States

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2.1 Introduction

Quantum systems display properties that are unknown for classical ones, such as the superposition of quantum states, interference, or tunneling. These are all one-particle effects that can be observed in quantum systems, which are composed of a single particle. But these are not the only distinctions between classical and quantum objects – there are further differences that manifest themselves in composite quantum systems, that is, systems that are comprised of at least two subsystems. It is the correlations between these subsystems that give rise to an additional distinction from classical systems, whereas correlations in classical systems can always be described in terms of classical probabilities; this is not always true in quantum systems. Such non-classical correlations lead to apparent paradoxes like the famous Einstein Podolsky Rosen scenario [1] that might suggest, on the first glance, that there is remote action in quantum mechanics.

States that display such non-classical correlations are referred to as *entangled states*, and it is the aim of this chapter to introduce the basic tools that allow to understand the nature of such states, to distinguish them from those that are classically correlated, and to quantify non-classical correlations.

2.2 Entangled States

Composite quantum systems are systems that naturally decompose into two or more subsystems, where each subsystem itself is a proper quantum system. Referring to a decomposition as “natural” implies that it is given in an obvious fashion due to the physical situation. Most frequently, the individual subsystems are characterized by their mutual distance that is larger than the size of a subsystem. A typical example is a string of ions, where each ion is a subsystem, and the entire string is the composite system. Formally, the Hilbert space \mathcal{H} associated with a composite, or *multipartite system*, is given by the tensor product $\mathcal{H}_1 \otimes \cdots \otimes \mathcal{H}_N$ of the spaces corresponding to each of the subsystems.

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