Protecting Quantum resources from noise, English Abstract

Quantum technologies, a diverse and rapidly expanding field, are at the forefront of a modern scientific revolution. Harnessing the intrinsic properties of quantum mechanics, these technologies have the potential to revolutionize many fields apart from physics, such as cryptography and computer science.

Among these new features, the capability of quantum matter to be in a superposition of states is certainly the furthest from a classical physical intuition. Turns out that a computer whose logical bits are made from quantum particles, i.e. a quantum computer, can exploit this property to hasten certain algorithms by a significant amount.

Another property fundamentally connected with the quantum world is entanglement, a phenomenon where the quantum states of two or more particles become correlated in such a way that the state of one particle is dependent on the state of another, even when they are physically separated. This feature too is a key part of many quantum algorithms. Those are the reasons why these properties are regarded as "resources" to perform computations or other technological tasks.

Unfortunately, these very valuable features for technological applications are very fragile if the systems exhibiting them are not isolated, and there is no such thing in the physical reality as an isolated system. When a quantum computer is exposed to its environment, for example, interactions with external particles or radiation can disturb the delicate superposition of states, turning a quantum bit into a classical one, only able to assume values 0 or 1 in a deterministic fashion. This phenomenon is called decoherence and it constitutes the main cause of errors and performance degradation of quantum algorithms. The entangled particles must remain isolated from external influences too, to preserve their unique entangled states. Unlike classical computers, which are relatively robust and resilient to external influences, quantum computers are then highly sensitive to their surroundings due to the delicate quantum states they rely on. This sensitivity has significant implications for the design and operation of quantum computing systems.

In order to extend the lifespan of quantum states and enable longer computation times, quantum computers must be then shielded from decoherence-inducing factors, such as temperature fluctuations, electromagnetic radiation, and vibrations, or must operate in a highly controlled and isolated environment.

The first attempts to protect a quantum machine from the noise induced by the environment are quantum error correction codes, where, using extra qubits, it is possible to recover part of the information lost due to the noise. In this thesis, we will provide other protocols or scenarios in which it is possible to preserve or enhance quantum resources stored in noisy quantum systems. The work will be structured as follows:

In Chapter 1, we will describe a general framework to study various quantum resources in a unified way, the so-called Quantum Resource Theories.

In Chapter 2, we will describe the way a quantum system interacts with its environment and how this interaction leads to the loss of coherence, putting the accent on a particular property of the reduced dynamic of the system, the so-called Markovianity.

In Chapter 3, we will first show that, for longer times, Markovian dynamics always destroy correlations between a system in evolution and an isolated qubit ancilla, a very valuable resource in informational tasks, and that the best way to preserve those correlations is to consider a dynamics which is non-Markovian at any time.

In Chapter 4, we will study a kind of map that helps preserve resources if applied as pre-processing before the noise acts, i.e. the dilution map.

In Chapter 5, we will answer a slightly different question, i.e what the optimal protocol to generate resource is if we equip a resource theory with a resource-generating map.