Preface

A tracking chamber is a device in which atoms or sub-atomic particles are detected and their dynamical life (generally very short by the standards of our everyday life) is recorded.

The classical description of what happens in the chamber is very well established and sounds entirely conceivable: the particle, emitted, for example, by a radioactive source, interacts with the microscopic constituents of a large environment kept in an unstable state. Local modifications of the environment, triggered by many small interactions with the moving particle, are enhanced by the long-range nonlinear interactions among the environment constituents to become the macroscopic footprints of the particle passage.

The observed tracks of the particle passage appear, in fact, as straight or curved lines which are properly described as trajectories of a classical particle in a classical electromagnetic field. For a theoretical description of the process the quantum character of the particle dynamics must be taken into account. In particular, it is relevant that the initial state of the particle emitted by the source does not have the form of a semi-classical wave packet (i.e., well localized in position and momentum) but rather that it is in a highly correlated superposition state, e.g., a spherical wave. Thus arises the nontrivial problem of explaining how such a superposition state can produce the observed classical trajectories.

In the standard approach, based on the so-called “orthodox” interpretation of quantum mechanics, a possible explanation is given considering the environment as a classical object that causes the “collapse” of the wave function of the particle.

In other words, the environment is interpreted as being a “measurement apparatus” that gives rise to the transition from the quantum behavior of the particle to the classical observed behavior of the particle in the chamber.

Nevertheless, a different point of view is worth considering. In fact, since the early days of quantum mechanics, the description of the observed dynamics of a particle in a tracking chamber (the Wilson cloud chamber in those days) generated an intense debate. Two main features made the case of particular interest: (i) there is no straightforward interpretation of the cloud chamber’s supersaturated vapor as a measurement apparatus: what does it measure? This leaves unspecified consequences and timing of the wave function collapse and, (ii) in principle the process of ionization of the vapor atoms might be dealt with in pure quantum mechanical terms.

Taking these aspects into consideration, another approach has been proposed in which the observed tracks ought to be explained as the outcome of the entire system Schrödinger's dynamics (of the particle and of the environment), instead of being deduced to be the consequence of the wave function reduction axiom.

In 1929, Mott (1929) examined such a possibility. In spite of its undeniable interest, Mott's detailed perturbative analysis remained almost unnoticed until recently.

Since the 1960s, there have been new investigations into the border between classical and quantum, measured system and measuring apparatus, starting with the theoretical work of Bell (1987) and with a few accurate experimental investigations. These works motivated the first attempts at modeling quantum measuring apparatuses and thermal baths. Of particular relevance to the field was the study of decoherence induced in quantum systems by interaction with an environment and the consequent emergence of a classical behavior in quantum systems (Joos et al. 2003).

The case of a particle in a tracking chamber is a prototypical example of classical behavior induced by the environment which, in our opinion, has received insufficient attention in the literature. A more detailed examination of this case study, based on a rigorous analysis of quantum models of the whole system, could be of great significance for a more profound comprehension of the conceptual structure of quantum mechanics and of its connection with the classical world.

This monograph provides a historical introduction to the problem of particle tracks in a cloud chamber and a quantitative account of recent attempts to describe a particle in a tracking chamber.

In Chap. 1 we provide a brief summary of some basic facts about the original Wilson chamber and describe a few early attempts to explain the observed tracks based on quantum mechanics. We then give a detailed account of Mott's 1929 paper to emphasize its role in pioneering the investigation into the dynamics of a quantum particle in a quantum environment. We conclude the chapter with an outline of successive studies on some related topics.

Chapter 2 is devoted to a detailed reformulation of Mott's three-particle model in a completely time-dependent setting. In order to have a simpler description of the forces confining electrons to the atoms of the chamber we use point interaction potentials. A different model-atom of the quantum environment is successively analyzed where the electron is harmonically bound to a force center in a fixed position.

In Chap. 3 we consider a quantum environment made of localized spins or, much the same thing, of two level atoms. We will use, as a technical tool in the construction of such an environment, the theory of multi-channel point interactions.

Our primary aim in Chaps. 2 and 3 is to present perturbative and non-perturbative strategies to characterize qualitatively and quantitatively the Schrödinger dynamics of a quantum particle in an array of model-atoms.

For simplicity, in some cases proofs of the main results are only outlined. The reader is referred to the original papers for more details.

In Chap. 4 we collect some concluding remarks where we also list few open problems we consider particularly relevant.

In the appendices we give a survey of the standard point interaction theory and we recall some elementary facts about the spherical wave.

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