

Preface

Magnetism is truly a very old subject. The first reference to a magnetic material, magnetite or the famed loadstone, can be found in Greek literature in astonishingly early times like 800 B.C. Yet the subject remains modern. It appeals to extremely basic issues of physics—magnetism as a material property is a direct result of one of the fundamental forces of nature governed by electromagnetic interactions. At the same time, this property forms the core of technology, influencing power-generation, biomedical applications through, for instance, magnetic resonance imaging, computer industry with the aid of memory devices and chips, just to name a few. Our objective in this volume is not to dwell on the myriad applications of Magnetism but to highlight the rich structure of its theory. It is remarkable to recount how many extraordinary ideas of physics ensue while teaching a course in Magnetism. To mention some: the first instance of velocity-dependent potentials in Mechanics is encountered in treating the Lorentz force on a charged particle in a magnetic field, the first example of the violation of time reversal is stumbled upon when we consider the Zeeman interaction of a spin in an external magnetic field, and so on.

Given this background to the wide applicability of the concepts of Magnetism, the purpose of these Lecture Notes is to further amplify how the subject has influenced developments in other diverse areas of Physics and how models used in Magnetism can help to clarify a variety of apparently unrelated phenomena. Magnetism is essentially a quantum mechanical subject. Yet its classical limits such as those described by Heisenberg or Ising-like models have far reaching applications to a

plethora of topics in phase transitions. Thus, while the ideas of symmetry-breaking and scaling first appeared in Magnetism, they soon pervaded other topics of not just condensed matter physics, but even distant terrains of field theory and high energy physics. Similarly, the concepts of disorder and frustration, embedded in magnetic spin glass systems, are also common to structural glasses. In the domain of non-equilibrium effects too, examples derived from Magnetism help to elucidate the underlying issues of relaxation and dissipation.

With the preceding preamble, the Lecture notes are chapter-wise divided as follows. Chapter 1, consisting of three sections, deals with the by-now well-known phenomena which first appeared in the context of Magnetism but have had important bearing in many other subjects. In section 1.1, we discuss the Mermin-Wagner-Berezinskii theorem on symmetry-breaking in the context of the Heisenberg magnet and its implications in ϕ^4 field theory. The latter forms the backbone of section 1.2 that is devoted to universality and consequent scaling relations which are the underlying concepts in critical point phenomena. In section 1.3 we discuss the issue of multicriticality and point out how the models originally introduced to describe this phenomenon in what are called metamagnets, found their application to tricritical points in $^3\text{He} - ^4\text{He}$ mixtures and even to bicriticality and tetracriticality in an open, nonequilibrium system such as a two-mode ring laser. From chapter 2 onwards, we turn to more recent topics. In chapter 2, we introduce the contemporarily relevant topic of the quantum critical point, again in the context of the Ising model but now in a transverse magnetic field, which finds its realization in rare-earth magnetism. The model helps illustrate the occurrence of quantum phase transitions in a variety of phenomena. The same model allows us to deal with the inter-connected concept of disorder and frustration, which is the subject of chapter 3. Again, the important ideas were first observed in dilute magnets alloyed with metals, called spin glasses. In chapter 4, we move from equilibrium to nonequilibrium statistical mechanics and show how the well-established ideas of spin-lattice and spin-spin relaxations, which are at the heart of magnetic resonance systems, can be further developed to obtain coarse-grained models of phase ordering and pattern formation, seen in many systems as competition between nonlinear interactions and

nonequilibrium effects. In chapter 5, we discuss important nonequilibrium phenomena seen in an assembly of single-domain nanomagnetic particles. The concomitant relaxation and memory effects are found to be a consequence of the interplay between polydispersity and inter-particle interactions. Similar memory or aging effects are observed in very different systems of relaxor ferroelectrics, shape-memory ferroelectric materials and structural glasses. The concepts discussed in chapter 4 in the context of magnetic response and relaxation behaviour find their counterparts in the recently-developed subject of dissipative quantum systems, discussed in detail in chapter 6. Therein we analyze the significance of coherence to decoherence transitions using a magnetic paradigm of Diamagnetism, which is intrinsically a quantum phenomenon, for which the boundary of the container plays a critical role. Thus dissipative diamagnetism is prototypical of decoherence in mesoscopic structures. Our final example is from a large spin quantum system that finds its realization in molecular magnets, and in which mesoscopic quantum tunneling can be seen. The influence of environment-induced dissipation makes this system yet another example of observing coherence to decoherence in quantum to classical crossover phenomena.

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