

Chapter 1

INTRODUCTION

Magnetically ordered amorphous magnets exhibit a wide range of interesting phenomena involving the nature of magnetic ordering, the dynamical interaction between spin excitations and the electronic transport phenomena. This first chapter is devoted to the introduction of the basic entities related to the electronic and magnetic phenomena in amorphous magnets. In amorphous magnets, a long-range magnetic order is possible, while the long-range order does not exist in the distribution of constituent atoms. These magnetic systems are classified three categories (ferromagnet, ferrimagnet and noncollinear spin structure). The general information and definition are given of the natures of these categories. For such systems we simply assume that the magnetic moment resides in and about the paramagnetic atoms. In the last section, we shall adumbrate some important physical properties of the structure in amorphous magnets.

1.1 Amorphous Magnets

We are usually concerned with the electrical and magnetic properties in an idealized crystalline magnet where the identical magnetic atoms occupy the sites of a regular crystal lattice. In an ideal crystalline magnet, the representation of physical properties can be simplified by the existence of translational symmetry. Mathematically, we refer to invariance under the translational operation of a lattice; the physical situation at a site \vec{R}_i on the lattice can be exactly reproduced at every other point by the basic translations, namely

$$\vec{R}_j = \vec{R}_i + \vec{l} = \vec{R}_i + l_1 \vec{a}_1 + l_2 \vec{a}_2 + l_3 \vec{a}_3, \quad (1.1)$$

where \vec{a}_i ($i=1-3$) are the fundamental translation vectors and l_i ($i=1-3$) arbitrary integers. The set of points \vec{R}_j defined by (1.1) for all l_i defines the lattice. These translations form an invariant subgroup of the space group, whose operation defines the Bravais lattice of crystal. For each Bravais lattice, the set of three vectors \vec{a}_i ($i=1-3$) defines the unit cell. The assertion of translational symmetry means that for some function $f(r)$ this must be a periodic function

$$f(\vec{R}_i) = f(\vec{R}_i + \vec{l}) \quad (1.2)$$

Accordingly, one can analyze $f(r)$ as a Fourier series;

$$\begin{aligned} f(\vec{R}_i + \vec{l}) &= \sum_k f(k) \exp(i\vec{k} \cdot (\vec{R}_i + \vec{l})) \\ &= \sum_K f(K) \exp(i\vec{K} \cdot \vec{R}_i) = f(\vec{R}_i) \end{aligned} \quad (1.3)$$

where K are reciprocal lattice vectors with

$$\vec{k} \cdot \vec{l} = 2\pi \times \text{integer} \quad (1.4)$$

The periodicity in an ideal crystalline magnet is often broken in an alloy where an atom of element A in a regular crystal is replaced by an atom of another element B with almost no disturbance of the crystal lattice. Then, the substituted sites do not need to form a regular lattice. When element A is magnetic and element B is nonmagnetic, the system is called a dilute magnetic alloy. In a dilute alloy, nonmagnetic atoms are randomly distributed on the regular lattice. These alloys constitute a class of disordered systems.

What is an amorphous magnet? An amorphous magnet can be often made by rapidly quenching its liquid state. Magnetic and nonmagnetic atoms in an amorphous magnet lose completely the periodicity of lattice in its crystalline counterpart and form a noncrystalline solid, like an oxide glass; The structural disorder is at the heart of the characteristic aspects of an amorphous magnet which are not found in the corresponding crystalline magnet. The key to the difference between crystalline and noncrystalline solids is that no two atomic sites are equivalent in amorphous substances, whereas all macroscopic directions may be equivalent in the bulk.

At this place, one should note that "amorphous" and "disordered" do not mean the same thing. "Amorphous" refers to the lack of a crystalline lattice, which implies that amorphous magnets are disordered. But not all disordered magnets are amorphous. As noted above, there are disordered crystalline alloys. For example, in a random solid solution of magnetic

elements, the atomic positions are fixed by the crystal structure but the magnitude of the localized magnetic moment varies in an aperiodic random fashion. A spin glass is a dilute solution of a magnetic element in a nonmagnetic host crystal, in which the atomic positions are fixed but the spin distribution is random. The spin system of solid solution compounds is periodic in magnitude and spacing, but may be aperiodic in the strength of the exchange interaction acting between a pair of neighboring spins. For comparison, a classification of disorder in magnetic systems is shown in table 1.1. Thus, amorphous magnets constitute a class of systems with the highest level of disorder. The main concern of this monograph is the introduction of the magnetic and electronic properties of these most disordered systems.

Table 1.1 Disorder in Magnetic Systems

Systems	Atomic Positions	Spin Positions	Spin Magnitudes	Exchange Interaction
Crystalline elements	Order	Order	Order	Order
Spin glass	Order	Disorder	Order	Disorder
Solid solution alloys	Order	Order	Disorder	Disorder
Solid solution compounds	Disorder	Order	Order	Disorder
Amorphous magnets	Disorder	Disorder	Disorder	Disorder

There is now a rich variety of amorphous magnetic materials that exhibit spontaneous long-range magnetic ordering below a critical temperature being characteristic to each substance. That is to say, although the long-range order for the distribution of magnetic atoms does not exist, a magnetic long-range order is possible in these systems. Therefore, these amorphous magnets can be mainly classified into three categories according to the nature of long-range magnetic order. In the next section, we present general information and definitions about the natures of these three categories.

1.2 General Information and Definitions

Crystalline magnetic materials are in general classified into four categories according to the nature of long-range magnetic order. These are called ferromagnetic, antiferromagnetic, ferrimagnetic, and helimagnetic systems and correspond, respectively, to parallel, antiparallel, uncompensated antiparallel, and spiral alignment of magnetic moments. Because of the structurally disordered nature, there exists a number of amorphous magnets with new-type spin orderings not classified by those of crystalline systems. In this section,