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ORDER PLEASES REASON BUT DISORDER DELIGHTS THE IMAGINATION (Paul Claudel)

MAGNETIC GLASSES
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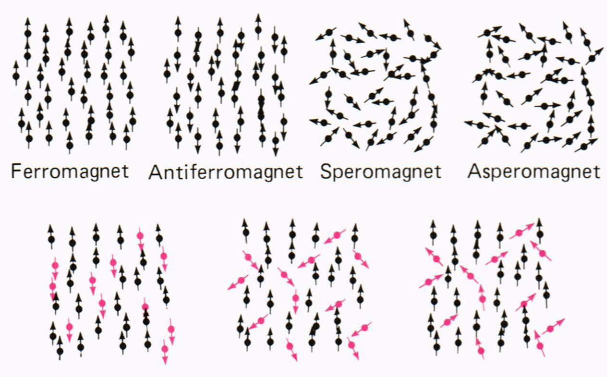
The field of amorphous materials and, in particular, amorphous magnetic materials has engendered considerable excitement in the communities of condensed matter physics and materials science. It is a field of virtually explosive growth as measured primarily by the published literature and secondarily by the growth of amorphous-material-based devices. As the authors of the book point out in their introduction, there is a paradox here. Insulating glasses doped with transition elements (for color) have been produced since ancient times with almost no attention by physicists to the magnetics. On the other hand, it took less than 10 years from Pol Duwez' demonstration of a method of producing metallic glasses to the appearance of thousands of papers, the convening of numerous conferences, and the publication of review articles on magnetism in amorphous metallic materials.

This research source book about amorphous metallic alloys is comprehensive and well written. Its principal emphasis is on the magnetic properties of the alloys. Secondary emphases are given to amorphous insulating materials (e.g., oxide glasses) and to metallurgical considerations underlying the formation of the amorphous state.

The introductory chapter treats the occurrence of chemical disorder in metallic glasses and its effect on the basic magnetic interactions to be expected in these systems. Concepts of nucleation, viscosity, quench rate, glass transition temperatures, diffusion, and solid-liquid phase equilibrium are introduced and discussed in an understandable fashion. The effect of topological disorder on the basic magnetic interactions in amorphous structures is discussed in terms of percolation theory, exchange distributions, random anisotropy, and frustration due to antiferromagnetic interactions. The categories of order to be found in magnetic glasses are displayed in this chapter, which sets the framework for the heart of the book and is itself a short course in magnetism. The categories include the familiar ferromagnetic order, antiferromagnetic and ferrimagnetic order discussed in the standard texts, and disordered-induced variations of these called speromagnetism, asperomagnetism, and sperimagnetism. (The terminology for the latter structures was actually introduced by Coey in a study of the magnetic properties of rare-earth/cobalt alloys.)

Chapters 2 and 3 describe various quenching methods for preparing metallic glasses and the nature of each, along with a discussion of various structural characteristics such as thermal and temporal stability and microstructure. The principles underlying the determination of average structural properties by neutron and X-ray scattering techniques are discussed with examples, including partial-pair correlation functions. The results of diffraction-determined radial-distribution functions are compared to information obtained from dense random-packed models and other structural networks.

The observed dependence on alloy composition of bulk or average magnetic properties such as bulk magnetization, Curie temperature (and other types of spin transition temperatures), and hyperfine fields is discussed in Chapter 4 for a variety of amorphous transition-metal alloys. The hyperfine distributions are particularly revealing and reflect the exchange distribution of the amorphous magnets; they also illustrate



Possible magnetic configurations of two-dimensional amorphous structures. The direction of the arrows indicates the orientation of atomic magnetic moments (from Moorjani and Coey, pp. 33 and 35). Red dots refer to a second atomic species.

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the natural evolution from ferromagnetic to spin-glass phenomena observed in many systems. Contact is made with theoretical calculations of the effect of the amorphous network on the bulk properties. The chapter concludes with a discussion of spin waves, critical phenomena, and scaling, and the results of experiments.

The occurrence of antiferromagnetic interactions in predominantly insulating glasses and the relationship to rings and subnetworks are discussed in Chapter 5, with many examples drawn from the large group of experiments on these systems, which really represent one of the oldest classes of amorphous magnetic solids. Many strong similarities are evident between these glasses and metallic glass as discussed elsewhere.

Rare-earth-based amorphous alloys present unique magnetic phenomena due to the presence of a strong, local, crystal-field interaction that is random in magnitude and direction. Chapter 6 gives a thorough conceptual discussion of the effects of the resulting random single-ion anisotropy. The occurrence of fan-like spin structures of various types (and newly coined names), as dictated by the relative types and balance of exchange and anisotropy energies, is reviewed along with their manifestations in the magnetization, remanence, hysteresis, and other bulk properties. A brief discussion is included of the destructive effect of random anisotropy on long-range ferromagnetism, and of the recent theory and experiments that demonstrate that these random anisotropic rare-earth alloys are probably more like spin glasses than true long-range ordered ferromagnets. The simpler case of gadolinium-based alloys that exhibit only exchange disorder effects is also discussed, with ample results from a wide variety of experimental studies. Included in this chapter are results from extensive studies of the transport properties and heat capacity of amorphous rare-earth alloys.

The discussion of rare-earth amorphous magnetism leads naturally into Chapter 7 on spin-glass systems and the vast amount of experimental and theoretical work in this field in the last decade or so. The term "spin glass" was originally applied to a static spin freezing phenomenon without long-range order observed in certain crystalline alloys of magnetic elements in nonmagnetic transition and noble metal hosts. But it was soon recognized that many of the peculiar magnetic properties displayed in these alloys are shared by amorphous rare-earth alloys. Previously introduced concepts of exchange distributions, competing interactions, and anisotropy are again reviewed in the context of the formation of the spin-frozen (spin-glass) system. In the study of spin glasses, a dichotomy has developed among theories that propose the existence of a true thermodynamic phase transition with a static order parameter versus those that predict a system with long-term, but still not infinitely slow, spin fluctuations. The authors describe in intricate detail the former set of theories. The magnetic phase diagrams of a variety of spin-glass systems are presented, including those leading to the experimentally observed phenomena of reentrant spin-glass behavior in which a ferromagnet undergoes a low temperature transition to a spin-glass state with an apparent absence of long-range magnetic order. Current theory is unable to confirm the existence of such reentrant phenomena,[1] but it does predict a low-temperature state of concurrent ferromagnetic and spin-glass order that is also consistent with a variety of experimental observations.

The final chapter includes a review of the unique properties of amorphous alloys that suggests potential applications and the effects of post-quench processing on these properties. Soft magnetic materials and their applications as well as hard magnetic alloys and their device potential are reviewed. The applications of soft magnetic materials to power transformers, motors, shielding, etc. are discussed. The applications of hard magnetic alloys to bubble memories, permanent magnets, delay lines, and magnetostrictive transducers, among others, are also discussed.

Overall, the book can be recommended highly as a resource book for both current research workers in the field of amorphous magnetism and as a good general overview of the status of the field for interested scientists in related fields. The assessment of experiments in the early part of Chapter 7 and those in Chapters 5 and 6 are the best parts of the book; they are well written, thorough accounts of research almost to the present. The earlier chapters on structure and characterization of materials are important for an understanding and visualization of the structure of glasses and how these structures are determined. The intelligent organization of the material, especially in Chapters 5, 6, and 7, is surely due to the authors' active involvement in research in amorphous magnetism.

The reference lists in each chapter are quite extensive and are significantly enhanced by a cross-reference index by author, chemical formulation, and specific subject. The book does an excellent job of laying the groundwork for the basis of amorphous magnetism, and it will likely have its longest lived impact in that area. Its discussion of the most recent experimental and theoretical studies will unfortunately slip out of date, as the field is rapidly evolving, producing several thousand papers per year. However, this will not detract for a long time from the carefully developed fundamentals of amorphous magnetism exhibited in this treatise.

REFERENCE

[1] M. Gabay and G. Toulouse, "Coexistence of Spin-Glass and Ferromagnetic Ordering," *Phys. Rev. Lett.* **47**, 201 (1981).