

Statement of Research Interests

(P. Chandra)

What are the essential features underlying the physics of glass formation? Glass is a non-equilibrium state of matter that persists on millenium time-scales; this dramatic violation of the ergodic hypothesis remains an outstanding challenge to workers in statistical mechanics. A glass is an intrinsically non-random solid that is structurally disordered but mechanically rigid. Furthermore its low-temperature properties depend on its sample history, and thus it has a memory of its past behavior. Although glass formation in the absence of intrinsic disorder occurs in a wide variety of physical systems, a simple underlying description of this ubiquitous phenomenon has yet to be found.

In a parallel but related development, there is now a growing list of anomalous antiferromagnetic materials that do not display conventional spin order. An outstanding example is URu_2Si_2 , a heavy fermion material with a mysterious second-order transition whose characterizing features cannot be reconciled with its observed tiny moment. There also exist several two-dimensional frustrated systems that display coexisting short-range spin correlations *and* low-energy magnetic excitations, suggesting new forms of spin order associated with “liquid-like” and even “glass-like” phases. The identification and characterization of such “moment-free” spin states could yield insight about questions well beyond the description of specific magnetic materials.

Theoretically the most detailed studies of glassy behavior have been performed on infinite-range systems with intrinsic disorder. Spin systems are often the theorist’s choice for reductionist models, since their basic components (spin) have no internal structure. The principal focus of my research for the last few years has been the detailed study and characterization of spin systems, both ordered and disordered, that do not develop spin crystalline ground-states. What are the key ingredients necessary to develop a short-range periodic spin system that displays glassiness? What are the similarities/differences between glasses with and without intrinsic disorder? How similar/different are periodic glasses with short-

vs. long-range interactions? How does the introduction of quantum fluctuations affect the behavior of a system with an extensive classical degeneracy?

The theoretical challenge is to identify and characterize a minimalist model for glassiness, analogous to the Ising model for second-order phase transitions. It is anticipated that the detailed study of intrinsically non-random glasses will lead to insights in other areas, possibly including content-addressable data storage and alternative optimization algorithms. A better understanding of degradation effects may also have direct practical applications. For example, identification of intrinsic contributions to fatigue and imprint in ferroelectrics may suggest relief treatments for existing non-volatile devices to optimize performance. Finally the study of decoherence in a quantum glass, determined by the structure of its density matrix, could give important insight for the identification of a physical setting for quantum computation.

These preceding questions and issues motivate my current course of study; I try to maintain a spectrum of projects including abstract theoretical studies and phenomenological approaches to novel materials. Here I summarize three distinct themes of my current research program:

(i) Nonequilibrium Quantum Dynamics

The design, development and control of nanoscale electronics raises many challenging questions, particularly in the area of quantum systems far from equilibrium. Such mesoscopic devices are often weakly coupled to their environment, so that equilibration is difficult. Common issues are shared by diverse problems including quantum dots, driven Josephson junctions and finite-size quantum glasses. There now exist controllable quantum systems far from equilibrium that are accessible to both theory and experiment. My collaborators and I plan to address global issues in this area through a series of specific studies, using the conceptual links between nonequilibrium spin systems and disordered interacting electrons. It is also clear that nonequilibrium sources of electron decoherence must be better understood in order to optimize performance of nanoscale circuitry, especially that which involves

quantum dynamics.

In general, the field of quantum systems far from equilibrium is a burgeoning one, particularly in the area of quantum glasses. The classical analogues of these systems display broad relaxation spectra; furthermore their long-time behavior depends explicitly on details of sample history. To date, the introduction of quantum fluctuations in these glassy models has not led to qualitative changes to their long-time dynamics. Recently my collaborators and I have identified a quantum critical point in a model that may provide a good setting for coherent quantum aging. In this system we plan to explore whether there exists a self-generated decoherence time. This general issue is crucial for the construction of quantum circuitry; even if each quantum element is designed optimally, there is the possibility of self-generated dephasing.

(ii) Novel Magnetic Order

There now exist several magnetic materials that do not display conventional spin order. An outstanding example is URu_2Si_2 , a heavy fermion material where the order responsible for the sharp specific heat anomaly at $T_0 = 17K$ has remained unidentified despite almost twenty years of effort. In URu_2Si_2 , the coexistence of large electron-electron repulsion and antiferromagnetic fluctuations leads to an almost incompressible heavy electron fluid, where anisotropically paired quasiparticle states are energetically favored. Motivated by recent nuclear magnetic resonance measurements, my collaborators and I have proposed the presence of incommensurate orbital antiferromagnetism, associated with circulating currents between the uranium ions, can account for the local fields and the entropy loss observed at the $17K$ transition. We have made detailed predictions for neutron scattering measurements based on this proposal, so that it can be tested experimentally. The next step is to explore the local crystal-field physics associated with the proposed itinerant excitations, and to study the field-sensitivity of the incommensurate orbital antiferromagnetism.

(iii) Ferroelectric Studies

Increasing clock speeds and decreasing voltage standards require an improved under-

standing of the coercive field (E_c) for the design and fabrication of competitive, non-volatile ferroelectric memory devices. In particular E_c is observed to increase as a function of increasing frequency and decreasing thickness. A 5.0-volt 200-nm FeRAM designed with $E_c(50 \text{ Hz})$ simply will not switch at 100 MHz . Furthermore the global aim of 0.5 V for silicon logic levels in the next ten years will require thinner films to achieve complete saturation and thus good retention. The controlled reduction of E_c as a function of frequency and thickness is thus crucial for the development of future generations of ferroelectric devices. My collaborators and I have addressed distinct weaknesses in the our current understanding of the thickness-dependence of the coercive field. For thin-films we have emphasized the importance of field-penetration in the electrodes and its impact on device performance. Preliminary studies indicate the importance of nucleation-dominated switching in the frequency-dependence of E_c , and we also plan to characterize the perimeter-dependence of E_c for films of diminishing area.