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BOOK REVIEW

Magnetoconvection. By N. O. Weiss and M. R. E. Proctor. Cambridge University Press, 2014. 432 pages, ISBN 9780521190558.

Thermal convection is a fundamental mechanism of heat transport on a variety of scales, from the kitchen to the cosmos. Convection in electrically conducting systems with embedded magnetic fields such as planetary cores, stars, accretion disks and clusters of galaxies is a particularly rich phenomenon and is the subject of this book.

Magnetoconvection is deeply implicated in the origin, evolution and dynamical behaviour of magnetic fields in magnetoconvective systems, and in how the field affects the structure of the system on small to large scales. Taking the Sun as a paradigm, it is fair to say that without magnetoconvection in the outer one-third of the solar envelope the Sun would rotate in a different manner, there would be no corona or wind, no activity cycle and no signatures of activity such as sunspots and flares. This would be fortunate, because without magnetoconvection in the Earth's core there would be no terrestrial magnetic field to shield our planet from solar emanations. A corollary is that neither the compass nor its metaphorical counterpart, the moral compass, would ever have been invented.

The conditions for onset of thermal convection have long been well understood. Static equilibrium of gravitationally stratified fluid with spatially localized heating and cooling typically requires both a pressure gradient to balance gravity and a temperature gradient to conduct heat. The equilibrium is unstable to convection if small displacements which maintain pressure equilibrium but not thermal equilibrium result in buoyancy. The system may then transition to a state in which heat transport by convection partially supplants heat transport by conduction. How the transition from linear growth to nonlinear saturation occurs is complex, and dependent on the parameters of the system.

For certain purposes, such as the calculating the structure and long-term evolution of stars, the average properties of the nonlinear convective state are all one really needs to know. Indeed, given the disparity in time scales – several hundred seconds for the turnover of small-scale eddies near the solar photosphere *vs* nearly 10^{10} years for the solar life cycle – this is the only practical choice. Subgrid modelling of heat transport by convection, empirically calibrated by a few observationally determined parameters, successfully explains many properties of stars. However, understanding by-products of convection such as chemical mixing, momentum transport and magnetic field evolution requires a more detailed picture of convection. While the large range of length and time scales in these problems still argue for subgrid approaches, their accuracy is less conclusive.

Increasingly, therefore, studies of magnetoconvection are carried out by direct numerical simulation. Although simulations have proven indispensable for nonlinear fluid dynamics problems they attain their full explanatory power only when accompanied by an analytic framework. Linear stability theory and dimensional analysis are powerful analytic tools, but are limited in scope, and can even be downright misleading. Intermediate steps such as nonlinear analysis or numerical calculations with simplified low-order dynamical models are needed to close the gap. And it is there, in the integration of nonlinear dynamics with advanced computation, that this book, written by two of the most accomplished masters of the area, really shines.

To a considerable degree, the book is self-contained. An early chapter on basic magnetohydrodynamics presents the essentials and four equally succinct appendices review aspects of nonlinear dynamics and fluid mechanics that are not explained in detail elsewhere in the book. Analytical and numerical studies of magnetoconvection are at their most advanced in the so-called Boussinesq approximation, according to which density variations are accounted for only insofar as they produce buoyancy. Five chapters take the reader through the linear and nonlinear theory of Boussinesq magnetoconvection in both inertial and rotating systems. A number of current research topics are treated, such as transition to chaos and pattern selection, and there is detailed discussion of amplifying and sustaining magnetic fields at large and small scales by magnetoconvection-driven dynamos. Analysis and computation are mingled throughout and many references are given, some classic, others as recent as 2014.

Compressible magnetoconvection is not as well understood as Boussinesq magnetoconvection. Nevertheless, the authors build on the Boussinesq case to present a remarkably complete chapter on the subject that touches many of the same topics discussed in greater detail for Boussinesq systems in the preceding text. As in the early chapters, the presentation is an artful mix of analytical and numerical results. The final chapter is a discussion of solar and stellar magnetic fields. Its placement is an interesting choice, and quite revealing. Many books that are primarily theoretical in nature begin with a motivational chapter on observations and phenomenology, sometimes never to return there. In contrast, the final chapter of *Magnetoconvection* can be fully appreciated only by a reader educated in the theory. It is a tribute to the authors' own faith in the strength and relevance of the foregoing material that they have placed this chapter last.

The level and expository style of the book are appropriate for an advanced student or researcher in the field. Derivations are presented in more detail than is typical of journal articles, the prose is clear, and the style is sufficiently pedagogical to teach the reader methods and concepts that could be applied elsewhere.

While *Magnetoconvection* is not written as a textbook – there are no problems or worked examples – working through it could be a very useful group undertaking in a specialized seminar. Were I to lead such a seminar, I would make two amendments to the material that the authors might wish to consider online or in a future edition of the book. First, to facilitate dipping into topics out of sequence, I would create a glossary of symbols. Second, I would give an introduction that places the chosen model – resistive, viscous, thermally conducting fluid – in the wider context of other models such as ideal fluids, radiation dominated fluids and collisionless plasmas that are appropriate to other natural systems. Clarifying the regime of validity of the model can help researchers in other areas to apply results selectively, and may spur more and broader research into the rich and fascinating subject of magnetoconvection.

Ellen G. Zweibel
University of Wisconsin-Madison, USA
zweibel@astro.wisc.edu