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REVIEW

Solar Magnetohydrodynamics. By E. R. PRIEST. Reidel, 1982. 469 pp. £59.75 hbk, £22.95 pbk.

Astronomers and laymen have always been fascinated by the Sun. When Galileo first observed sunspots through a telescope his discoveries captured the attention of poets, scientists and cardinals alike. That was 370 years ago but sunspots are still not properly understood. Meanwhile, optical telescopes have become more powerful, and X-ray and ultraviolet measurements have been made from space. All these observations have revealed a bewildering variety of behaviour, dominated by the presence of magnetic fields. Solar magnetic features offer many challenges to the theoretician. We are constantly reminded that (as E. N. Parker puts it) Nature is cleverer than we are; and one can only admire the confidence with which other astrophysicists explain phenomena on much more distant and exotic objects.

The Sun is the only star whose surface can be observed in any detail. The magnetic features that are seen are often interesting in themselves. They are also important to astrophysicists because of their implications for other stars that seem to exhibit similar behaviour. For fluid dynamicists the Sun provides a unique laboratory in which a wide range of hydromagnetic behaviour can be observed. The relevant parameter values are inaccessible in experiments on earth and so our understanding of solar magnetohydrodynamics depends mainly on theoretical investigations.

Professor Priest has produced an excellent textbook, written from the viewpoint of an applied mathematician and with an emphasis on modelling magnetic structures in the photosphere and above. This is the region where theoretical predictions can be compared directly to the observations. Theories of the solar interior are harder to check and, perhaps for that reason, receive only a cursory treatment in this book. Observations of photospheric, chromospheric and coronal structures are, however, fully described and the author consistently relates his mathematical models to these observations. There is also a remarkably full list of almost 600 references, going up to 1982.

About half the book is occupied with introductory or basic material. The first chapter provides a summary of solar physics. Anyone wanting a more extended account should read R. W. Noyes's outstanding book (*The Sun, Our Star* Harvard, 1982), which describes the physics without recourse to mathematics and so supplements the treatment here. Out of the many magnetic features on the Sun, Priest selects sunspots, prominences and flares as posing the most fundamental questions to a theoretician.

This is followed by five chapters that provide an introduction to magnetohydrodynamics. He first reviews the basic equations, flux-freezing and the behaviour of current sheets and flux tubes. Then he considers magnetohydrostatic equilibria, with a valuable discussion of force-free fields. Next come waves to suit all tastes: acoustic, magnetic, internal and inertial, singly and in various combinations. There is a short chapter on hydrodynamic and hydromagnetic shock waves and, finally, a fairly full account of hydromagnetic stability. Here he uses both the energy-principle and the normal-mode approach, and provides a useful catalogue of instabilities to be found in astrophysical or laboratory plasmas. This section of the book might be taken on its own as a basic course in magnetohydrodynamics, superseding older texts by

Cowling and Roberts. Astrophysicists could also use it as a convenient introduction to continuum mechanics.

The chapter on sunspots covers several topics. Sunspot umbrae are cool because the magnetic field is strong enough to inhibit overturning convection. So magnetoconvection is treated at some length, with a clear account of linear theory and of some nonlinear results. That leads naturally to a discussion of magnetic buoyancy and the instabilities of stratified magnetic fields, which provide a mechanism for producing the isolated flux tubes that emerge in active regions. The actual configuration of the field beneath a sunspot remains controversial. The traditional picture of a single magnetic plug is oversimplified but may be qualitatively correct. Moreover, it allows one to construct simple equilibrium models and to study their stability. Within the convective zone, magnetic flux is apparently confined to isolated tubes, which float upwards owing to magnetic buoyancy and emerge vertically through the photosphere. The equilibrium and stability of thin, isolated flux tubes have also been investigated. Tube waves contribute to heating of the atmosphere above but in a superadiabatically stratified layer a tube collapses, draining itself downwards, unless the field is sufficiently strong. This evacuation is held responsible for intense magnetic fields in the solar photosphere. However, there is still no adequate model that relates adiabatic collapse within a flux tube to the ambient convective flow.

The chapter on dynamo theory is the only one that approaches the solar interior. The author has wisely decided to present a concise review rather than compete with Moffatt's book. So he discusses the basic ideas of kinematic dynamo theory and mean field electrodynamics, and then uses an α–ω dynamo model to illustrate the generation of magnetic cycles. There is a short discussion of nonlinear dynamos, with a brief but sceptical reference to chaotic oscillators: the author reminds us that 'strange attractors exhibit fascinating behaviour and are attractive in themselves' but do not necessarily explain anything. This is in the spirit of a chapter that begins with Cowling's theorem and ends by listing all the weaknesses of dynamo theory at present!

The rest of the book is principally concerned with detailed modelling of magnetic structures in the solar atmosphere, a subject where Professor Priest and his collaborators have made distinguished contributions. Their work demonstrates how classical applied-mathematical techniques can be used effectively in astrophysics when the models are sufficiently constrained by observations. The first problem is the heating of the chromosphere and corona. Forty years ago, it came as a surprise when the temperature was found to increase from a minimum of 4000 K (at the boundary between the photosphere and chromosphere) to 3×10^6 K in the corona. This high coronal temperature is responsible for thermal X-ray emission and for generating the solar wind. The rival heating mechanisms are wave processes and magnetic dissipation. It now seems that slow magnetoacoustic waves can heat the chromosphere. Coronal heating depends on magnetic fields, which dominate its structure, but it remains unclear whether the dissipation is produced by nonlinear Alfvén waves or in quasistatic current sheets.

Within the atmosphere, the most obvious static features are loops, prominences and coronal holes. The simplest problem is to explain how magnetic fields support quiescent prominences against gravity. This sounds like a straightforward application of magnetohydrostatics – but Nature is clever and the issue turns out to be more complicated than expected. On the other hand, the formation of prominences, through a thermal instability, has been fairly satisfactorily explained. This mechanism depends on the sensitivity of the radiative loss function to variations in temperature: it is salutary for fluid dynamicists (who are happier with the Boussinesq approximation) to face up to processes caused by the vagaries of radiative transport in plasmas that are optically thin.

Flares are bound to be more difficult. Here the problem is to explain the sudden release of energy, on a timescale of tens of minutes. As Priest remarks, 'there are as many flare theories as flare theorists'. Fortunately he is prepared to be selective and so manages to produce a semblance of order in a subject that often seems confusing. It is generally accepted that the energy released can only be stored in the magnetic field, which may be gradually built up. The flare itself is produced by rapid reconnection in a current sheet, caused by instability or lack of equilibrium. Gas flows into the sheet at a fraction of the Alfvén speed. With the work of Petschek, Soward and Priest (among others) the associated shock structure is now understood. It is not so easy, however, to explain how the current sheet is formed, though several models of simple loop flares and two-ribbon flares are carefully discussed.

Finally, we come to the solar wind. Biermann first proposed a wind in order to explain why comet tails point away from the Sun. Parker's spherical wind solution (like Bondi's spherical accretion) is beautifully simple. It also provides one of the few examples in solar physics of a theoretical prediction that was subsequently verified by observations, when the first satellites found a supersonic wind. We have since learnt that the geometry is more complicated, owing to the large-scale magnetic field, and that the wind is dominated by high-speed streams, emerging from coronal holes along open field lines. The rate of loss of angular momentum by the solar wind is exactly calculated by assuming corotation out to the Alfvénic point. This is another nice result, though it is a pity that Priest only derives it for spherical symmetry, following Weber & Davis, instead of presenting Mestel's more general axisymmetric treatment.

Magnetic braking has important consequences. We now know that the magnetic activity of a star depends on its rotation rate. During its lifetime on the main sequence the Sun has gradually spun down and reached its present genteel level of activity. Unfortunately, this book scarcely mentions the solar–stellar connection. Just as solar physics helps to explain the properties of other late-type stars, so we can learn more about the Sun by studying similar stars at different stages of their evolution. Solar oscillations also receive inadequate attention; the five-minute oscillations are treated as a photospheric phenomenon rather than as global oscillations of the Sun. Helioseismology is now an important subject and has made significant progress since this book was published.

The obvious comparison is with Parker's monograph (*Cosmical Magnetic Fields*, Oxford, 1979). Parker's book is based largely on his own work; he conveys a sense of excitement and offers penetrating thoughts. Priest's volume surveys the subject more systematically and would, therefore, be more useful for a graduate course. Indeed, much of its strength comes from the author's experience in teaching, which gives the book an easy style. One can recognize informal remarks that went down well in lectures. They are usually helpful – but not always: at one point he asserts that 'every Scot who heats his pan of porridge oats knows that, when the bottom of the pan is hot enough, the porridge starts to bubble away and exhibit a cellular circulation'. In England, Jeffreys pointed out in 1926, porridge burns unless it is stirred, because it is so viscous that the critical Rayleigh number is not reached; hence it boils but does not convect.

These are, however, minor blemishes. Professor Priest has constructed an impressively coherent textbook. As an account of solar magnetism, or a demonstration of the applied-mathematical approach in astrophysics, it can be strongly recommended. When the book was first published the price was fixed at a level where only well-heeled libraries would buy it. Now it is available in paperback at a reasonable price and I urge all those who are interested in the subject to go out and get it.

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