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REVIEWS

Foundations of Radiation Hydrodynamics. By D. MIHALAS and B. W. MIHALAS. Oxford University Press, 1985. 718 pp. £55.00.

Astrophysical Radiation Hydrodynamics. Edited by K. A. WINKLER and M. L. NORMAN. Reidel Publishing Co., 1986. 590 pp. Dfl 235 or US$ 98 or £69.95.

Apart from an appendix on the elements of tensor calculus, the first of these books divides into two parts: the first part, comprising chapters 1–5, focuses on the dynamics of non-radiating fluids; and the second part, chapters 6–8, adds to that treatment by the inclusion of radiation effects. In so doing, the authors have attempted to approach the problem from the standpoint of a 'composite fluid, consisting of material particles and photons', thus making the subject of radiation hydrodynamics more accessible to a wider audience than the radiation specialists. In that respect it should appeal to the more conventional fluid dynamicist – though workers in this area will find that the book lacks the lustre of the better-known fluid mechanics texts. In the preface to the book the authors mark out the primary goal as being 'to expose the great foundation-stones of the subject, and to erect upon them solid, if incomplete, walls of methodology on which others can later build'. Some astrophysicists will be disappointed that the incompleteness shows itself in the limited discussion of applications and examples. Nevertheless the astrophysicist who wishes to understand the basics necessary to establishing a working knowledge and understanding of fluid dynamics would do well to study the book carefully.

Chapter 1 deals with the microphysics of gases, leading into that subject via the macroscopic description that thermodynamics affords. The account is easily read and sets out the essential results, as briefly as possible. Chapter 2 deals with the dynamics of a compressible ideal fluid and the main features of fluid motion – all within 26 pages. Chapter 3 extends the discussion to real fluids with the inclusion of viscous and heat-conduction effects, defining in the process the usual important flow parameters. The chapter is rounded off by approaching the equations of motion from the kinetic theory point of view, again rather brisk but workmanlike, presenting the tools only. With none of the usual examples of fluid motion given, texts on fluid mechanics will have to be referred to if the reader wishes to discover what the mathematics means in terms of physical description. The conventional fluid dynamicist may find himself not altogether au fait with chapter 4 on relativistic fluid flow, but it is worth studying, if only to begin to taste the astrophysical flavour.

By far the largest constituent of the first part of the book is chapter 5 which deals with waves, shocks and winds, highlighting those effects which are of astrophysical importance. It begins with an account of acoustic waves and acoustic-gravity waves, and the reader is introduced to the ideas of group velocity, dispersion and polarization. Interaction of waves with different layers of gas is as important in the astrophysical environment as it is in the terrestrial, and such phenomena as reflection, refraction, tunnelling and trapping are dealt with. The theory is illustrated by examining the structure of the solar atmosphere. Shock wave theory follows next, with the nonlinear steepening of a simple wave – it is a pity that the theory does not adopt a full characteristic approach, since when and where simple wave theory applies does not emerge. The jump conditions and structure of shocks then follow. Added phenomena of interest are relaxation and ionization effects. Weak-shock theory is touched upon, perhaps with a feeling of apology but as the authors remind the reader, the theory 'provides useful insight into the physics of shock propagation'. It is this kind of insight, particularly by way of simple modelling, which is somewhat lacking in this chapter. Of course, in astrophysical problems nonlinear phenomena are all-important and one must resort to the use of either numerical methods, or, in the case of simple situations, similarity solutions. The latter can be a great aid to the behaviour of shocks and the book does illustrate this with reference to the propagation of a blast wave driven by a point explosion and the propagation of shocks through a density stratification. However, the main tool in the solution of gas dynamical problems today is numerical simulation; this is touched upon by the authors, though not in sufficient detail to give the reader a feel for the power or the limitations of existing methods. The chapter ends with a discussion of thermally driven winds.

This takes us to approximately half-way through the book, and the remainder harnesses to radiation what the reader hopefully will have learned on the subject of fluid mechanics. Chapter 6 sets the background scene on radiation and radiative transfer, and its interaction with material. It provides, in a fairly readable and concise way, an introduction to the necessary ingredients needed to master the dynamics of radiating fluids. This follows in chapter 7, which for the conventional fluid dynamicist will be a little overpowering. Here the reader will arrive at the equations of radiation hydrodynamics which as the authors remark, 'in two- and three-dimensional flows are truly formidable' – quite so. Thankfully they confine themselves to one-dimensional flows. Radiation diffusion methods in which the material is extremely opaque are discussed together with a careful appraisal of the asymptotic procedures. The computational strategy for solving the resulting equation ends the chapter. The final chapter can be read in more relaxed mood, at least the reviewer found this to be true, as it examines some examples of radiating flow. The effects of radiation on the structure of shocks is thoroughly treated. The authors then turn to propagating shocks using weak-shock theory to begin with and then strong shocks with the aid of similarity and numerical modelling. There follows a selection of problems of astrophysical interest, among which there are the shock heating of the solar chromosphere, supernova explosions and ionization fronts.

In summary, as a text for a researcher entering the subject of radiation hydrodynamics for the first time, the book does fulfil its aim in 'exposing the great foundation stones', but to the reviewer the building erected is perhaps left a little too incomplete; nevertheless it is a book to be recommended for serious study by both fluid dynamicists and astrophysicists.

The second book under review contains the proceedings of a Nato Advanced Research Workshop held in Garching in 1982. Its subject matter is divided up into three sections: radiation hydrodynamics, gas dynamics, and relativistic flows, the contents of each being concerned either with the formulation of the relevant set of governing equations and/or their numerical solution.

It should be stressed that this is not a book for the uninitiated and that most of the articles are written from the perspective of a physicist. This approach is typified by the articles by Castor and Mihalas which between them present a thorough account of every conceivable physical effect that could be of relevance to the equations of relativistic hydrodynamics. This should be useful for anyone already acquainted with the area and wishing for a more detailed account of the physical basis of the equations he is trying to solve, but is likely to seem daunting to the newcomer to the field. Furthermore, little is given in the way of a conventional mathematical analysis of the resulting equations.

The articles devoted to the numerical solution of the equations of radiation hydrodynamics present their numerical algorithms in a descriptive manner with very little systematic explanation as to why one particular approach was adopted and not another. They cannot, therefore, be aimed at anyone unacquainted with numerical methods. However, for someone with some degree of expertise in this area, the work presented will be useful as an account of how these particular authors have tackled the problem.

The section on gas dynamics will perhaps disappoint anyone interested in the analytic solution of these equations, approximate or otherwise. The approach of the articles in this section is almost entirely numerical, and what discussion there is of the underlying nature of the equations can be rather bizarre. These papers do, however, give a representative sample of the numerical methods for the solution of the equations of gas dynamics available today. These cover finite-difference, finite-element, spectral and particle methods; there is even an article on turbulence modelling. In contrast to much of this volume, the articles on finite-element, particle and spectral methods are of an introductory nature, and do not present any numerical results. The only numerical results that are presented were produced by finite-difference techniques. Again much of the discussion of finite-difference methods is purely descriptive, nothing being presented by way of a systematic numerical analysis. Furthermore, serious students of finite-difference methods will perhaps be surprised that, with the exception of the article by Woodward, many of these methods are outside the mainstream of modern research into the numerical solution of the equations of gas dynamics. One is also struck by the sparseness of the comparison between numerical results and analytic or actual laboratory flows, at least in dimensions higher than one. In two or three dimensions numerical fluid flows are notoriously dependent on resolution, and one wonders how true this is of some of the results presented here.

The final section on relativistic flows is again primarily numerical. The articles within it are fairly wide-ranging: ultra-relativistic fluid dynamics, neutrino transport, relativistic gravitational collapse and the characteristic initial-value problem in general relativity (the sole mathematically biased contribution in the proceedings). Again, the work presented is not for the novice, but may be of value to those with numerical experience.

The subject matter of this book provides a fairly representative, but by no means exhaustive, sample of some of the most challenging problems currently being tackled by researchers in astrophysics. The numerical approach adopted in the bulk of these proceedings is a reflection of the extreme difficulty people find in tackling the relevant equations analytically. It is to be hoped it will encourage those with experience in terrestrial areas of hydrodynamics and numerical analysis to take an interest in the subject.

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M. J. Wilson

Ferrohydrodynamics. By R. E. Rosensweig. Cambridge University Press, 1985. 344 pp. £45.

Ferrohydrodynamics refers, as the name suggests, to the study of the motion of fluids which can exhibit levels of magnetization comparable with those of solid ferromagnetic materials. Although natural paramagnetism and diamagnetism have been observed in many liquids and gases, the forces which can be applied to them by the action of practical magnets are too weak to have aroused the interest of fluid dynamicists. It has been the successful development of colloidal suspensions of solid ferromagnetic particles in liquid carriers that first produced fluids capable of being magnetized to interesting levels – interesting, that is, not only for the range of novel phenomena which can be studied for their own sake, but also for potential engineering application. Recently it has been found possible to fluidize beds of solid ferromagnetic particles in gas flows, providing a new area of ferrohydrodynamic activity.

Dr Rosensweig has been associated with ferrohydrodynamics ever since the name of the subject was first coined and appeared in the title of a paper which he coauthored in 1964. His enthusiasm for the subject and his infectious delight with the tricks which ferrofluids can perform leave a memorable impression from the monograph under review. It would indeed be a dull fluid dynamicist who could read it without responding to that enthusiasm.

A first reaction to ferrohydrodynamics might well be to regard it as no more than providing a new body-force term to be introduced in the Navier–Stokes equations. There is certainly a level at which a ferrofluid can be treated as a continuum with body forces appropriate to local-equilibrium conditions of magnetization. The magnetization vector $\boldsymbol{M}$ is assumed to be aligned with the intensity vector $\boldsymbol{H}$ and it is also assumed that there are no hysteresis effects, so that the magnitude M can be taken as a single-valued function of H for given temperature and density, say. Then classical thermodynamic arguments can be used to find the magnetic stress tensor. It turns out that magnetization of the fluid gives rise to an irrotational force field if M is a function of H only, but there is also an influence on the boundary condition on normal stress. It follows that at this level of ferrohydrodynamic theory interest centres mainly on the shaping of free surfaces, on interfacial waves and on interfacial stability. (Although flow about an immersed body is not affected by the irrotational force field, the situation is still of some interest because the net force on the body can be changed and give rise, for example, to stable levitation.) The monograph gives many examples of phenomena which have been analysed and observed experimentally. Interfacial ferrohydrodynamic behaviour seems to be particularly photogenic and many striking pictures are reproduced – this reviewer's nomination for an Oscar would be the labyrinthine patterns formed when a thin layer of ferrofluid is confined between parallel plates and subjected to a magnetic field normal to the plates.

The magnetic-force field may become rotational if there are temperature gradients, so that account must be taken of the dependence of magnetization on temperature as well as H. The influence of this dependence can become particularly strong if the temperature ranges across the Curie point of the solid particles. The use of magnetocaloric effects has been proposed for heat engines with ferrofluid as the working substance, and the effects have also been investigated in the context of problems of thermal convection.

However, anyone studying the colloidal ferrofluids will soon appreciate the need to take account of their colloidal nature. A good ferrofluid will be 'designed' to maintain dispersion of the magnetized particles in the face of interparticle forces and under the action of magnetic-field gradients. In practice particles tend to migrate to regions of high magnetic-field strength and the magnetic properties of the fluid are then no longer strictly uniform. As far as the reviewer is aware, there has been no investigation of large-scale phenomena resulting from this effect. What has deservedly been a source of much research activity has been the problem of how to take account of finite time for relaxation to equilibrium magnetization. The solid particles are of subdomain size and they behave like small permanent magnets, with random orientation in the unmagnetized state and with their alignment for the magnetized state being opposed by thermal agitation. When there is a rapid change in magnitude or direction of the magnetic field as experienced by a fluid element, inertia of the solid particles or viscous resistance to rotation may mean that the state of magnetization is not one of local equilibrium. (The brief description here takes no account of the Néel mechanism.) Of particular fascination is the possibility of the magnetization vector $\boldsymbol{M}$ not being aligned with the intensity $\boldsymbol{H}$, so that there is an effective body couple $\mu_0 \boldsymbol{M} \times \boldsymbol{H}$ and there is no reason for the viscous stress tensor to be symmetric. Continuum equations for ferrofluid behaviour in terms of an internal 'spin', together with plausible constitutive relations have been developed. However, there is a serious quantitative discrepancy between the predictions of the modelling and the experimental results of Moskowitz & Rosensweig (*Appl. Phys. Lett.* vol. 11, 1967, p. 301) for the rotation of a ferrofluid in a stationary cylindrical container when subjected to an applied rotating magnetic field. A particular aspect which appears to be uncertain is the appropriate boundary condition on the internal spin at a solid surface. In general, ferrohydrodynamics with non-equilibrium magnetization is not yet as firmly based as the equilibrium case.

Many threads have to be drawn together in a full description of ferrohydrodynamics and Dr Rosensweig's task in writing the monograph cannot have been an easy one. His aim has been 'to produce a work that is sufficiently self-contained to be accessible to engineers, scientists, and students from many fields'. The monograph begins with an introduction to magnetism, magnetic-field theory and basic fluid-mechanic concepts. This is followed by a useful chapter on the colloidal science of ferrofluids, their preparation and their properties, before the ideas of the introduction are amplified with chapters on electromagnetism and the magnetic stress tensor for equilibrium magnetization. The next chapters are on the application of the ferrohydrodynamically modified Bernoulli equation, on magnetocaloric energy conversion and on instabilities. The monograph ends with a chapter on effects associated with non-equilibrium magnetization such as relaxation and asymmetric stress and a chapter on magnetic two-phase flow.

There are many good things in this monograph, and it provides a valuable compilation of ferrohydrodynamic problems that have been analysed. Whether Dr Rosensweig has successfully overcome the difficulty inherent in his stated aim is perhaps best left to the judgement of those coming to ferrohydrodynamics for the first time. An example of one area that might raise doubts is the transition from the initial treatment of the magnetic field of poles and dipoles to discussion of overall effects in terms of the magnetization vector $\boldsymbol{M}$. The serious student will find the 'concluding comments and supplemental references' at the end of each chapter a helpful guide to further reading.

M. D. Cowley