REVIEWS

The Sea. Volume 1: Physical Oceanography. Edited by M. N. HILL. Interscience, 1962. Pp. 864. £9. 8*s*.

Twenty years ago, a book was published whose influence on oceanography has been pervasive. It was *The Oceans* by Sverdrup, Johnson and Fleming; a medium-sized book, homogeneous in style, rather descriptive and having all oceanography as its scope. In those days, the science consisted of a fairly compact group of subjects, and *The Oceans* gave a brief and masterly account of them. The intervening time has seen great activity, and the subjects have grown in breadth and depth. Some have developed from the infancy of the forties to maturity (or adolescence, at any rate) in the sixties; others unborn then are lusty youngsters now. Even the parents of the family, the exploratory and observational parts of oceanography, have changed almost beyond recognition as a result of new efforts and new techniques. No longer can a single volume contain even a survey of the various branches of the subject, and no longer can one man write with authority on them all.

This is the first of a series of three volumes, subtitled 'Ideas and observations on progress in the study of the sea'. Its declared intention is to provide a comprehensive treatise on work accomplished during the twenty years since *The Oceans* was published; to give 'a balanced account of how oceanography and the thoughts of oceanographers are moving'. It contains the work of thirty-three authors; it is large, heterogeneous and deals only with physical oceanography. Its quality has turned out to be very uneven, the best of the contributions being superb and the worst embarrassing. In spite of this, its publication is an important event. It is certainly the most valuable book of its kind.

The first section, on 'Fundamentals' contains two chapters. Fofonoff summarizes the physical properties of sea water. Carl Eckart discusses the equations of motion and thermodynamics in his characteristic manner, and develops his scheme for solution of these equations by successive approximations about a state of rest. He is sometimes deliberately provocative and those raised on Lamb's *Hydrodynamics* will not find him dull.

Section 2 is concerned with the large topic 'Interchange of properties between sea and air'. Deacon and Webb, writing on the small scale interactions, give a concise and balanced account of the relevant observations and physical parameters involved in the interchange of momentum, heat and water vapour. 'Large scale interactions' by Joanne Malkus is one of the highlights of this volume. It is long (200 pp.), almost a monograph in itself, beautifully written and intellectually stimulating. The atmosphere and oceans are intimately connected as parts of an open thermodynamic system controlling our climatic environment. The diversity of processes encountered and the interplay among them makes this a fascinating (though often inadequately understood) topic. Dr Malkus's description of it is memorable.

Fofonoff's second contribution is a careful, if rather formal, review of some aspects of the dynamics of ocean currents. This topic also is characterized by the relevance of a variety of dynamical processes, and is one of the most active areas of present research. Necessarily, Fofonoff's account takes the form of a series of examples, each illustrative of a particular set of phenomena but none really definitive. Many of the ingredients seem to be here, but an inclusive and correctly argued theory of the ocean circulation seems still to be a little way off. This is certainly a most valuable critical survey of the subject at the time of writing (1960).

Section 4 of this volume is concerned with the transmission of energy in the sea. The chapter entitled 'Light' by Tyler and Preisendorfer is remarkably uninformative and uncritical. Elementary ideas are dressed up in complicated formalism. Twelve pages are devoted to tables giving the radiance distribution in lake water at various depths as a function of azimuth and tilt. Half are for a 'clear sunny sky', half for an 'overcast sky'. Three significant figures are given yet the values given for these two ill-defined categories differ by a factor of about ten. The apparent completeness and accuracy of these extensive tables seems entirely spurious. Again, their figure 26 shows a photograph of 'an instrument for determining R, K and D' (previously defined optical parameters). It looks like a retort stand with a couple of light bulbs screwed into it. How does it work? What *are* those mysterious globes? Nowhere is any clue given. Fortunately, the poverty of this chapter is partly redeemed by some of the following ones. Clarke and Denton on light and animal life are brief and fascinating. The article by Liebermann ('Other electromagnetic radiation') is simple and to the point, as are the three on sound in the sea, its propagation, and its scattering and generation by marine life.

There is a long section on waves. Cartwright's chapter on 'Analysis and statistics' is sensible; his balanced presentation should do much to clarify a topic sometimes muddied by needless pseudo-sophistication. Rossiter writes on long-term variations in sea level, a tantalizing subject with wide implications, and again one in which many geophysical phenomena enter. Munk, on long ocean waves (periods 30 seconds to 12 hours), opens with: 'The most conspicuous thing about waves in this frequency range is their absence'. Yet by careful observation and interpretation of what he has seen, an astonishing variety of effects is demonstrated. This chapter is a delight. Barber and Tucker's contribution on wind waves is simple and clear, though little is said about the dynamics of the processes involved. The art of wave prediction still provides a substantial concern to them. Although this may have given some initial stimulus to the subject, its scientific importance is now surely slight. Darbyshire discusses the relation between microseisms and ocean waves and Cox gives an informative account of what is known about ripples. The first part (by Lafond) of the chapter on internal waves is rather superficial, consisting of some disjointed sets of observations and qualitative speculations on the possible relations between internal waves and slicks, tides or internal motions in basins. Cox's part is shorter, more penetrating and more stimulating. In ten pages, he presents the substance of the limited quantitative observations made so far, and faces important questions (such as the distinction between internal waves and other non-propagating modes of motion) that arise in interpretation of these data. Bowden's article on turbulence is a curious one. A few statements (for example, that local energy transfer from the mean motion equals the local dissipation rate, p. 808) are very misleading. Some of the topics (mixing-length theory, flow over the bottom) were old hat in aerodynamics thirty years ago. Others are borrowed from more recent work in micrometeorology, yet little indication is given about anything novel or challenging concerning turbulence specifically in the ocean. There *are* of course real questions. Why, for example, is the 'neighbour diffusivity' apparently proportional to $l^{\frac{4}{3}}$ over such a huge range of l (10 cm to 1000 km)? This is surely one of the major mysteries.

This is probably more than enough to show the nature of this volume. The editor is to be congratulated on what must have been a monumental task in the assembly of so much talent and the collation of their contributions. Some of these will certainly be of value in the years to come, and that is, I suppose, recommendation enough.

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Magnetohydrodynamic Shock Waves. By J. EDWARD ANDERSON. The M.I.T. Press, 1963. 226 pp. 49*s*. or $6.50.

This book represents the published version of a mature thesis submitted for the degree of Doctor of Philosophy at M.I.T. Anderson gives a comprehensive account of magnetohydrodynamic shock waves which is limited only to the extent that the analysis is based on the continuum theory of ionized gases. Besides making his own contributions, he covers the ground prepared by previous authors. However, the book does not provide a really useful introduction to the subject, although this was perhaps not intended and should not be expected. The failure is due to the complications in the analysis and in the presentation which do not appear to the reviewer to be always necessary and which are of sufficient intrinsic interest to warrant extended discussion here.

There are three principal aspects to the theory of shock waves, and Anderson takes each of them in turn. First, the shock can be treated as a discontinuity in a non-dissipative, perfectly conducting, fluid. The magnetohydrodynamic equivalent of the Rankine–Hugoniot equations and the condition that entropy cannot decrease in the direction of mass flow then determine possible upstream and downstream flow states for shocks. Secondly, the behaviour of a discontinuity when subjected to small perturbations caused by infinitesimal waves can be investigated. If the discontinuity can adjust to a perturbation by an infinitesimal change of strength, it may represent a stable shock wave which could be found in practice. Finally, a shock must have a steady-state structure in a real, i.e. dissipative, fluid. In the gasdynamics of non-conducting fluids every discontinuity predicted by the Rankine–Hugoniot equations and the entropy condition is found to represent a stable shock with a steady-state structure. The situation in magnetohydrodynamics is not so straightforward. Discontinuities are predicted which are unstable and for which a structure cannot be found. There are even discontinuities for which a structure can be found, and yet they appear to be unstable.

Anderson begins with the well-known classification of shocks and analysis of the Rankine–Hugoniot equations which are due to Germain (*Rev. Mod. Phys.* **32**, 1960, p. 951) and Shercliff (*J. Fluid Mech.* **9**, 1960, p. 481). The previous work is amplified with a discussion of perfect-gas relations of which a part is useful for later analysis of shock structure. However, the algebra associated with perfect gases is often more confusing than helpful, and Anderson, himself appears to be confused by it at one point. The definition which he chooses for the strong shock limit is not the same as Shercliff's strong slow shock as he claims. The limit implies in fact a negligible magnetic field strength, and the results which are derived are immediately obvious once this is realized.

The next section of the book, in which Anderson discusses the stability of shocks with respect to small disturbances, is undoubtedly the best. The Russian literature is well reviewed, and the section opens with a valuable discussion of magnetohydrodynamic waves. The theory of stability shows some curious features. It has been found that, as in ordinary gasdynamics, all discontinuities which satisfy the Rankine–Hugoniot equations but not the entropy condition can emit waves spontaneously and should therefore decay. Fast and slow magnetohydrodynamic shocks can emit just sufficient waves to satisfy boundary conditions at the shock if they are perturbed and are thus stable. However, difficulties appear in the case of the intermediate shocks, where the shock velocity relative to the upstream flow is greater than that of an Alfvén wave and relative to the downstream flow is less. One type, the 23 shock of Germain's classification, can emit magneto-acoustic waves spontaneously, and can be expected to decay. The remainder cannot emit sufficient waves to satisfy boundary conditions at the shock when submitted to certain perturbations. These are called non-evolutionary shocks. It is possible that they never occur in practice; Shercliff showed that the steepening of compression waves could not be invoked as a mechanism for their formation. If they are formed, perhaps they will subsequently break up in a violent manner, and it has been suggested for example that the normal shock, when classed as intermediate, splits up to form a switch-on followed by a switch-off shock. However, the latter are only limiting cases of the stable fast and slow shocks, and Anderson's linear analysis shows that small perturbations create large disturbances in the vicinity of the shocks. I am not convinced that this difficulty with switch-on and switch-off shocks could not be resolved by a full non-linear treatment. The claim here by Anderson that a linear Alfvén wave of finite amplitude could be the cause of the original disturbance and would lead to the same results is physically unreasonable. A finite Alfvén wave approaching a switch-on shock from upstream invalidates his assumption of one-dimensional flow.

The major part of the book is devoted to shock structure, and this is where most of Anderson's own contributions occur. A continuum approach is adopted, the ionized gas is treated as a single fluid, and the Hall effect is neglected. The equations are more complex than those used for example by Germain, since Anderson claims that effects due to electron inertia and charge convection can be important. I am doubtful about the order-of-magnitude arguments which he uses to support the claim. Anderson assumes that the shock thickness will be of the order of a mean free path, and this is said to be given by dividing the typical relative velocity of the shock by the electron-ion collision frequency. This is wrong. If the ion–ion collision frequency had been used in the calculation, the estimate for the mean free path of charged particles would be closer to the real value by an order of magnitude. However more thought is required before we can say that the shock thickness will be of the order of a mean free path.

There are several length scales associated with the dissipative processes occurring in shocks in an ionized gas, and I would have welcomed a complete discussion of them. In the fully ionized condition, momentum of the gas as a whole is carried by the ions, and, if we can assume that the mass velocity is of the same order of magnitude as the thermal velocity of the ions, convection and diffusion will be balanced in a length of the order of the ion mean free path, l_i say. Although the mean free path of the electrons is comparable with that of the ions, the random velocity is much higher, and thermal diffusion, for which the electrons are chiefly responsible, is then balanced with convection over a larger distance, $l_e = 0(m_i/m_e)^{\frac{1}{2}} l_i$, where m_i and m_e are the masses of ions and electrons. It is easily shown that the length scale for achieving thermal equilibrium between electrons and ions should also be l_e if elastic collision processes only are taken into account. The electrical resistivity introduces another length scale, l_m, such that the magnetic Reynolds number based on l_m is of order unity for most conditions, although a different scale may be more appropriate for slow shocks at very high magnetic field strengths. For a fully ionized gas it is interesting to find that the criterion for the neglect of the Hall effect is $l_m \gg l_e$, but for a partially ionized gas this condition, although necessary, will not be sufficient. Thus the only realistic ordering of the length scales for Anderson's assumptions will be $l_m \gg l_e > l_i$, which implies that throughout most of the structure all the dissipative processes can be neglected except that due to the electrical resistivity. Thermal conductivity and viscosity may be important in a subshock which is much thinner than the complete shock transition and which has the same properties as a shock in ordinary gasdynamics. If the thermal diffusion processes are to be studied in detail, then, strictly, allowance should be made for different temperatures of electrons and ions, as in the work of Jukes (*J. Fluid Mech.* **3**, 1957, p. 275). It would have been a more significant improvement in the realism of the model if Anderson's analysis had allowed for this departure from thermal equilibrium between species rather than for the effects of electron inertia and charge convection.

Anderson works in terms of the diffusivities rather than the length scales suggested above, but the greater part of his analysis is equivalent to choosing various orderings of l_m, l_e and l_i. He finds that a unique structure exists with any ordering for fast and slow shocks, although there is some difficulty over the density variation in the latter case. Here the statement that the density varies monotonically through slow shocks when electron inertia effects are absent is not always correct. Nor do I see why Anderson is chary of allowing for subshocks on the upstream side of slow transitions when the electrical resistivity is large.

The equation which governs transverse momentum appears to have the greatest influence in shock structure. It is a consequence of this equation that a state where the flow velocity equals the speed of propagation of an Alfvén wave cannot be reached in the one-dimensional flow of a perfectly conducting and inviscid gas except when the magnetic field is parallel to the direction of variation. Hence shear viscosity or electrical resistivity must be invoked if a shock structure is to be found for intermediate shocks. The 23 intermediate shock has a structure only for particular ratios of the diffusivities, and I believe these cases can be disregarded on the grounds that they are freaks. It appears that a structure can be found for the remaining intermediate shocks, always when $l_m \gg l_e$, sometimes when $l_e > l_m$, and, except for the normal shock, probably never when $l_i > l_m$. Viscosity alone is not enough to carry the solution through the point where the flow velocity equals the speed of propagation of an Alfvén wave.

There is an interesting connexion between the stability theory and the structure of shocks when the electrical resistivity is large. This is suggested by the recent work of Todd (*J. Fluid Mech.* **18**, 1964, p. 321, and in a private communication of work to be published later). There is no unique structure for intermediate shocks. For all of them the amount of internal magnetic flux in a direction transverse to the external magnetic field is arbitrary. It is precisely the transverse perturbations carried by Alfvén waves for which all intermediate shocks are non-evolutionary. Some intermediate shocks can also have an arbitrary structure which allows for varying amounts of magnetic flux in the plane of the external magnetic field. Perturbations which would introduce magnetic flux in this direction would be carried by the magneto-acoustic modes. Again it is precisely those intermediate shocks, and only those shocks, which have this second type of arbitrary structure that are non-evolutionary with respect to magneto-acoustic disturbances. By an alteration of their structure intermediate shocks may absorb small perturbations. A pattern of behaviour for shocks when the electrical conductivity is low begins to emerge. Perhaps the next important step will be to find how the behaviour is altered when the Hall effect is included in the analysis.

The book concludes with an appendix in which Heiser describes some experiments in an electromagnetic shock tube. There is some evidence that a normal gasdynamic shock is observed only when it can be classed as fast. For conditions under which a normal gasdynamic shock would be classed as intermediate if it occurred, a switch-on shock is observed. As Heiser remarks, a severer test of whether intermediate shocks can exist would be given by a gas-driven flow if that is practical. Experiments in a tube rather than in an annular passage would also be interesting since the transverse flux paths are less clearly defined, and the experimental arrangement is less favourable to the formation of a switch-on shock.

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