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REVIEWS

Basic Engineering Thermodynamics. By F. J. W. Wallace and W. A. Linning. Pitman, 1970, 532 pp. £2.00 (paperback).

A Course in Thermodynamics. Volume 2. By J. Kestin. Ginn-Blaisdell, 1968. 617 pp. $15.50.

Thermodynamics and Statistical Mechanics. By L. M. Grossman. McGraw-Hill, 1969. 323 pp. $13.50.

A Course in Statistical Thermodynamics. By J. Kestin and J. R. Dorfman. Academic Press, 1971. 577 pp. £17.50.

Nearly a generation ago the eminent thermodynamicist Joseph Keenan cautioned against "the attempt to expound thermodynamics in terms of the kinetic theory of gases" though he allowed "that each of these subjects illuminates the other." Continuing, he wrote "It would be best if all students of engineering would master both. But mastering both means mastering each, and that in turn means the acquisition of clear-cut definitions and principles for each science without qualitative or quantitative confusion between them." Concluding with the sternest of warnings (and apologies to the late Ogden Nash) he pled,

"Let's sink into the deepest ocean
The phrase 'heat is a mode of motion'...".

It was a timely piece of advice. The intervening score of years has brought a deluge of books on thermodynamics from both sides of the Atlantic. On balance their authors have been sensitive to the general problem and many appear to have heeded carefully the exhortation.

The latest spate of thermodynamics books includes four which suggest the range of approaches to the subject. Wallace & Linning follow a traditional path starting from macroscopic statements of the first and second laws and progressing through the concepts important in engineering thermodynamics. The third law is not considered. The only departures from a continuum treatment occur in chapter 9, which deals with the kinetic theory of gases, and in appendix I, which gives a simplified statistical treatment of entropy, despite the statement on the back cover about "...frequent references to the statistical or microscopic standpoint wherever this is helpful". The book is written as a text for a first course in thermodynamics for engineering students. Mechanical, civil and aeronautical engineering students are served best, chemical and electrical engineering students less well. There are no surprises in the material or order of presentation. The exposition of the material is generally clear and is assisted by simple uncluttered figures and numerical examples. Selected references and a modest number of problems, graded in difficulty, with answers, occur at the end of each chapter. Property tables and charts are not provided. The S.I. system of units is used and a conversion table is provided to assist the metrication process in progress in Great Britain and beginning in the United States.

The book is a readable representative of the traditional approach to undergraduate, macroscopic, engineering thermodynamics, undistinguished, in any important aspect, with respect to the best available.

A Course in Thermodynamics, Volume 2 concludes Professor Kestin's efforts "...to introduce the novice to the subject without making concessions in rigor, and preserving a logical deductive sequence in the presentation" and to convince future engineers and their teachers "that thermodynamics provides a natural, unifying basis for the scientific foundations of their profession". The first volume of 600 pages appeared in 1966 and introduced basic elements of the structure such as temperature, the equation of state, work, first law, systems and the second law together with an elaboration of the consequences and applications of these concepts for a variety of conditions. Volume 2 continues to add components of the basic structure: equilibrium and stability, pure substances in a single phase, chemical equilibrium in a single phase, equilibrium in heterogeneous systems, the third law of thermodynamics, and irreversible processes in continuous systems. Five chapters on statistical thermodynamics appear midway in the volume and are presented from the viewpoint of ensemble theory and quantum mechanics. Also included are forty-three tables, largely of thermodynamic data. Selected problems, requiring clear understanding of the material developed in the respective chapter and significant effort, are assembled in one place following the tables. (This volume differs in this respect from volume 1, which is curiously devoid of numerical problems or exercises, although a very wide variety of systems and processes are carefully treated in the body of the text and successfully demonstrate the wide applicability of thermodynamics.)

The role of thermodynamics in science and engineering education is a matter of continuing concern. Looming large are such matters as the extent to which classical thermodynamics should be covered, the appropriate place of statistical concepts, and the role to be given to irreversible processes in continuous systems. *A Course of Thermodynamics* makes two major contributions to the continuing debate. First, it develops carefully, clearly and rigorously the structure and scope of classical thermodynamics in such a way that the earnest student will become aware of both the universality and limitations of the subject. Second, the exposition of this structure reveals the relationships between classical thermodynamics, statistical thermodynamics and non-equilibrium thermodynamics. Workers in fluid mechanics particularly will welcome the manner in which bridges are built between their field and thermodynamics. Despite the scope of the two-volume effort, it is possible to select from the material presented a cohesive sequence of topics to form a rigorous first-year university course in classical thermodynamics; the author however declines to make that selection for others. For scientists and engineers active in fields where thermodynamics is of central concern or where it interacts strongly with central concerns, *A Course in Thermodynamics* will be a resource of enduring value.

Thermodynamics and Statistical Mechanics is conceived of by the author as a relatively compact introduction to the theoretical methods used in describing and predicting the properties of macroscopic systems, which are viewed as comprising a very large number of particles, in equilibrium with their surroundings. The most likely audience consists of those advanced undergraduate and beginning graduate students in engineering and the sciences with at least one year's study of advanced mathematics beyond the calculus. The material is organized into three distinct parts. The first comprises a quarter of the book and is a concise exposition of classical thermodynamics: the first law, the second law, thermodynamic potentials and equilibrium. With the same economy, the principles of statistical mechanics are set forth: quantum-mechanical foundations, statistical ensembles and microcanonical, canonical, and general canonical ensembles. The last half covers the determination of equilibrium properties of simple assemblies, first for weakly interacting systems, then for imperfect gases and condensation liquids, and crystalline solids. Five brief appendices develop pertinent equations and concepts. Each chapter concludes with a number of exercises designed to test the reader's comprehension of the theory in specific applications.

The approach is thus to discuss separately classical thermodynamics and equilibrium statistical mechanics as distinctly different, but complementary, ways of describing the same system. In the applications of the second half, the two viewpoints are interwoven. The succinct development of major themes sought by the author is achieved by the omission of important topics in both sections, classical thermodynamics and statistical mechanics. These theoretical sections are set in quite general frameworks which require the reader to have followed a solid first course in classical thermodynamics (e.g. *A Course in Thermodynamics*) and to have an acquaintance with elementary statistical physics. Moreover, the postulatory and formal approach followed in laying the quantum-mechanical foundations, while appropriate for the volume's goal, cannot do justice to the scope or, more importantly in this instance, the physical context of the subject of quantum mechanics. Thus many readers will find it necessary to refer to the references listed at the end of the chapters.

The appearance of *A Course in Statistical Thermodynamics* by J. Kestin & J. R. Dorfman is a not unexpected sequel to Kestin's *A Course in Thermodynamics*. The author's goal is an introduction to the methodology of statistical thermodynamics for students of biology, chemistry, engineering and physics at a time in their studies when advanced mathematical methods are not yet available. It is therefore an introduction which emphasizes the physical characteristics of the subject while avoiding distortions and inaccuracies.

As in the previous case, this text begins with a highly condensed review of the classical concepts and laws of thermodynamics; this can in no way replace the working knowledge of these topics the reader must have if he is to relate classical and statistical aspects. There follows, in chapters 2–6, an exposition of the fundamental theory of statistical thermodynamics. Except for chapter 2, which is introductory, the material of this part parallels that in *A Course in Thermodynamics, Volume* 2, while stressing the importance of a correct formulation of Gibbs ensembles in quantum-mechanical terms. The second half of the book is given to applications: properties of real gases, degenerate perfect gases, properties of solids, radiation, magnetic properties, kinetic theory of gases, the

Boltzmann equation and fluctuations. Noteworthy is the presentation of the kinetic theory as the classical limit of quantum statistics, which avoids the inaccuracies encountered when the kinetic theory is studied in isolation. In the applications section, the kinetic theory is used to understand elementary transport phenomena and to develop rigorously the Botzmann equation. To some this section may appear eclectic, and indeed, topics there may be taken up in any order which interests the reader. Most will agree, however, that the authors have carefully focused on the essentials and skilfully integrated the macroscopic and microscopic views by selecting that which gives greatest clarity in describing a particular physical phenomenon.

Problems are provided at the end of each chapter to test the reader's mastery of the material and selected problems solved in order to complete the developments in the main text. Graduate students and practitioners in the natural sciences and engineering with the requisite mathematical background can, with an effort and *Thermodynamics and Statistical Mechanics,* bring their understanding in this area to the level required to follow major developments. Students, young and old, approaching statistical thermodynamics with a macroscopic, continuum orientation and the intention of taking the full measure of the field, are, however, directed to *A Course in Statistical Thermodynamics.* Here they will find an approach which reveals the scope, unity and power of a story which continues unfinished because of the activities of those who take up its reading.

W. E. IBELE

An Introduction to Statistical Mechanics. By P. DENNERY. George Allen and Unwin, 1972. 118 pp. £3.00.

This well-done little book is a clear 'first approximation' for advanced students and non-specialists already familiar with thermodynamics and elementary quantum mechanics. The approach is modern: the whole development of the molecular description of thermodynamic systems is based on a single postulate, the "master equation", which determines the evolution in time of the many-body system. An appendix gives Pauli's derivation of the master equation from the Schrödinger equation. For each of the four chapters there are exercises, with hints and answers for a few. A judicious selection of references rounds off this introduction, which admirably succeeds in doing without the collection of ensemble theory postulates on which statistical mechanics has customarily been founded.

H. T. DAVIS

Non-equilibrium Thermodynamics. By I. GYARMATI. Springer-Verlag, 1970. 184 pp. DM 38.00 or $10.50.

This is one more monograph on irreversible thermodynamics, here defined as "the universal theory of macroscopic processes" based on "the theoretical principles" published by L. Onsager in 1931. In fact, Onsager's contribution is a set of reciprocal relations stemming from microscopic reversibility and the rest of non-equilibrium thermodynamics is classical continuum physics focused on irreversible processes, but restricted to linear constitutive relations, and informed by statistical mechanics and the kinetic theory. The best exposition of the hybrid subject remains S. R. de Groot & P. Mazur's *Non-equilibrium Thermodynamics* (North-Holland Publishing Company, 1962). Gyarmati has attempted, as have Prigogine and several others, to fashion a "unified field theory" and "universal variational principle" for dissipative, which is to say real, processes. The second half of this monograph is given over to "variational principles" which have only coincidental connexion with the mathematics of extrema of functionals, as codified in the calculus of variations. It is propagating an illusion to write, as Gyarmati does, of his "global form of the universal principle of least dissipation of energy", of Glansdorff & Prigogine's "total formulation of the principle of minimum production of entropy", and of "the integral principle of [non-equilibrium] thermodynamics...with the aid of [which] the pure mechanical (inertial) motion and the dissipative effects superposed on it can be treated simultaneously". Fluid mechanicists intrigued by this sort of language would do well to consult M. H. Protter & H. F. Weinberger's *Maximum Principles in Differential Equations* (Prentice-Hall, 1967) and compare the hard-won variational principles of Weinberger's recent case study of steady fall in Stokes flow (*Journal of Fluid Mechanics*, 1972, **52**, 321–344) with the things to which the same name is attached by the schools of Prigogine and Gyarmati.

L. E. SCRIVEN

Statistical Mechanics at the Turn of the Decade. Edited by E. G. D. COHEN. Marcel Dekker. 1971. 235 pp. £6.00 or $12.50.

Lecture Notes in Physics. Volume 7. Lectures in Statistical Physics. Edited by J. EHLERS, K. HEPP and H. A. WEIDENMÜLLER. Springer-Verlag, 1971. 181 pp. DM 18.00 or $5.00.

Taken together these two collections of lectures cover many of the important problems towards the solutions of which statistical physics has contributed significantly during the past decade. The eight lectures edited by E. G. D. Cohen (himself one of the lecturers) were presented at a late-1969 symposium commemorating the seventieth birthday of Professor G. E. Uhlenbeck, one of the leaders in the field. They have the flavour of a research seminar and reflect the current status of the subject. The second set of lectures is from an Advanced School of Statistical Mechanics and Thermodynamics held under Professor I. Prigogine's aegis at the University of Texas in 1969 and 1970. They are more didactic in nature and some of them overlap considerably.

In the first collection, A. S. Wightman's lecture on old and new results in ergodic theory marks renewed activity by physicists in a powerful type of analysis which can clarify the existence and nature of ergodic behaviour of mechanical systems: for example, J. Sinai has shown that the irreversible mixing flow suffered by a fluid composed of hard-sphere molecules confined in a box can be derived as a theorem of pure mechanics. An outstanding problem is to prove with kinetic theory that a moderately dense gas approaches thermal equilibrium, i.e. to prove an H-theorem. Cohen points out that for *no* extension of the Boltzmann equation beyond binary collisons does such a proof exist. Six of the lectures deal at least in part with the theory of phase transitions and critical phenomena. Beginning with Onsager's exact treatment of the two-dimensional Ising model, simple molecular models, especially those of lattice type, have yielded substantial insight into the molecular nature of phase transitions. These are nicely laid out in the lectures, which also provide valuable perspective of some of the leading unsolved problems that are within the grasp, or at least the reach, of statistical theorists: understanding the physical basis of the so-called scaling laws (a form of dimensional analysis) of critical phenomena, developing a dynamical theory of critical phenomena of equal rigour and applicability as the equilibrium theory, solving the series of problems of ferromagnetic phase transitions posed in F. J. Dyson's lecture, are just a few. Missing from this collection is any discussion of the important roles played recently by 'master equations' in elucidating the nature of irreversible processes and the approach to equilibrium, and in developing a rigorous statistical-mechanical theory of Brownian motion. Missing too are the developments in generalized hydrodynamics, by which is meant the theory of short-time relaxation and wave phenomena as well as familiar long-time transport processes, and the related use of time correlation functions.

These lacunae are partly filled by *Lectures in Statistical Physics*. R. Balescu in a short "Introduction to non-equilibrium statistical mechanics" derives by means of projection operators the master kinetic equation and shows how the irreversible behaviour of a so-called classical gas of weakly interacting molecules emerges in asymptotic limits to the exact equations. The longest and most informative lectures are on the equilibrium theory of phase transitions by the late Z. W. Salsburg and on dynamical effects at the critical point in fluids and magnets by P. Resibois; both are up-to-date, clear summaries (although the usage of such terms as "hydrodynamical regime" and "viscous mode" may be unfamiliar to fluid mechanicists). A short lecture by J. L. Lebowitz touches on questions of analyticity of the thermodynamic limit as the size of a system becomes infinitely large. It is believed that only in this limit can statistical mechanics account rigorously for phenomena such as phase transitions and irreversibility, which are peculiar to macroscopic systems. The opening lecture by I. Prigogine draws together critical phenomena, fluctuation theory and thermoconvective instability. The so-called Bénard problem of hydrodynamics is presented as an example of discontinuous change in structure due to dissipative processes in systems far from equilibrium; other examples are drawn from chemically reacting systems. Prigogine appears to suggest that hydrodynamic instability, chemical instability, and the dissipative structures to which they lead might be related to some manner of generalized, excess entropy production rate. Whether such a connexion exists is a controversial question on which the lecturer has written in several other places, some of them cited in this volume.

H. T. DAVIS

Introductory Gas Dynamics. By A. J. CHAPMAN and W. F. WALKER. Holt, Rinehart & Winston Inc., 1971. 591 pp. $12.50.

Thermofluid Dynamics. By A. J. REYNOLDS. Wiley, 1971. 680 pp. £7.50.

Compressible-Fluid Dynamics. By PHILIP Z. THOMPSON. McGraw-Hill, 1971. 665 pp. $17.50.

Chocs et Ondes de Choc. Edited by A. J. JAUMOTTE. Masson et Cie, 1971. 395 pp. 150F.

In recent years there has appeared a plenitude (one could almost say a plethora) of books claiming to cover, in whole or in part, that branch of the physical world which has to do with the flow of compressible fluids. The daunting task of providing a comparative review of four new books in this field leaves the reviewer with the feeling that one imagines the research staff of a consumer magazine must experience on being asked to report on a variety of makes of a marketable product. It seems appropriate therefore to follow their example by considering certain basic questions which naturally suggest themselves and then try to answer them by devising and applying particular tests. Such questions are, 'Do the books have similar aims? With what varying degrees of success are these aims achieved? Do they have anything to offer not already contained in existing books in the field? And, finally, what advice should one give to the prospective customer, the person who wishes to teach by or learn from a suitable textbook?'

First it should be stated that the objectives of the authors of these four books are not the same. To take Jaumotte first, very much an odd one out in this selection, the aim is to provide for engineers and research workers a unified treatment of the fundamental aspects of shock waves (a second volume is promised which will deal with applications). Thus, this (collaborative) work is not confined to non-conducting gases in the continuum regime but contains chapters which discuss, in addition, magnetohydrodynamic shocks and shocks in solids as well as shocks involving chemical reaction (detonation shocks) and the kinetic theory approach to the structure of shocks. The chapters are written independently by different, eminent, continental authors and there is little cross-referencing. The other three books, all introductory texts to the subject, are, broadly speaking, comparable in the sense that they begin and end at about the same point and many of the topics covered are common to them all; but they do not all envisage and address the same readership. Chapman & Walker and Reynolds direct their work toward engineering undergraduate students in the senior year (U.S.A.) and second or third year (England) respectively. Thompson, on the other hand, writes for senior and graduate students (U.S.A.) in "engineering, physics and applied mathematics". Since required prior reading for Jaumotte would consist at least of the material contained in the other books it is clear that it cannot be compared in aim or scope with them; nevertheless, in some instances comments made in the following paragraphs do apply to it.

One way of deriving a basis for comparison, or 'test', is to note how the different authors deal with related disciplines which necessarily encroach on to the subject of gas dynamics and to which some attention must be paid. Thermodynamics belongs to this class and the teacher usually has to decide between devoting a significant amount of time to the subject itself or introducing the minimum amount necessary 'to get by' as he proceeds. (Rarely, at least in Mathematics Departments, is there a specialized course in thermodynamics available.) In the reviewer's experience the latter method seldom succeeds whilst there is not usually enough time available to use the former satisfactorily. Reynolds has a fully comprehensive opening chapter on thermodynamics in which are described many simple examples and Thompson also adopts this approach without being either so complete or so fully equipped with illustrations. Only Chapman & Walker use the second method and they do presume "a prior knowledge of basic thermodynamics". At least, this requirement should prevent the situation from arising where a perplexed student, on being confronted with the Second Law of Thermodynamics (p. 18), asks, 'What about the First?', even if it does restrict Chapman & Walker's share of the market. But it is also important to explain how the science of thermodynamics, which deals with equilibrium states, can be applied to compressible-fluid mechanics where non-equilibrium processes are the norm. Only Thompson (briefly) and Reynolds (at greater length) mention the implications of this assumption. The point does not appear at all in Chapman & Walker except in passing in connexion with the discussion on a strong normal shock.

Again, one can ask about the impact on new gasdynamics books of the important and expanding volume of work being undertaken in non-continuum fluid dynamics with the application of the Boltzmann equation to the flow of rarefied gases and plasmas. Apart from the valuable chapter in Jaumotte already mentioned only Thompson pays any attention to this aspect, including a definition of a Maxwell velocity distribution function (but no collision integral) with the calculation of several of its moments, whilst it is not mentioned in Reynolds, and Chapman & Walker state simply that kinetic theory is beyond the scope of their book.

Much of the material in all three of the undergraduate books is concerned with inviscid flow of a perfect gas without heat conduction. One can then ask how this theoretical model is related by the authors to actual high speed internal and external flows or, to be specific, how is the rôle, for example, of the gas's viscosity presented? In Chapman & Walker it is barely mentioned in the entire book apart from minor exceptions dealing with frictional flow in diffusers and ducts. Reynolds, however, devotes a chapter to dissipative processes where "viscous friction" is introduced by reference to some simple one-dimensional laminar flows (Couette, Poiseuille and the flow due to an oscillating plate) and "turbulent friction" is discussed on the basis of dimensional analysis. Thompson alone obtains the equations for the flow in a compressible laminar boundary layer, in a section entitled "Laminar boundary layer behind a shock wave", and his treatment lasts scarcely a dozen pages although it does include an account of the Dorodnitsyn–Howarth transformation. What appears to be lacking in each of these three books is a clear statement in either physical or mathematical terms of the way in which the external flow (or Euler limit of the governing equations) and the flow in the boundary layer and wake (Prandtl limit) complement one another in providing a full description of an unseparated flow pattern at high Reynolds number. It is true that Reynolds refers to boundary layers on several occasions and even calculates the heat transfer across a turbulent one but it really does seem preferable in spite of the concern with practical engineering applications to explain the significance of a laminar boundary layer before postulating the existence of a viscous sublayer in turbulent flow.

In their treatment of shock waves each of the introductory texts adopts the same approach. Everyday examples are quoted, discontinuities are then assumed and the conservation conditions across them are derived by physical arguments in the standard manner. It is only at a later stage in each case that the question of shock formation is taken up. Whilst there are practical reasons for choosing this order of presentation (algebraic equations are more readily assimilated than partial differential equations) there is a strong logical and psychological motivation for discussing shock formation first. (It is interesting to note that the specialist book, Jaumotte, does adopt this order in the opening chapter.) Moreover, if sound propagation has already been introduced (as it had in Chapman & Walker and Thompson) the connexion between waves of infinitesimal and finite amplitude develops naturally. Reynolds defines a sound wave as a vanishingly weak shock (before, incidentally, an explicit definition of shock strength has been given). Again, the situation in real flows where the opposing effects of nonlinearity on the one hand, and viscosity and heat conductivity on the other, achieve a balance in the production of a shock receives scant attention.

Each of the introductory books is well endowed with problems appended to each chapter. Reynolds, in particular, provides a grand total of 314, graded into three degrees of difficulty and drawn from a very wide background. Chapman & Walker use f.p.s. units throughout, Jaumotte uses S.I. and the others use a mixture of the two.

It would be misleading to leave unmentioned individual strengths and failings. Chapman & Walker have written a book on gasdynamics which, as it will have emerged above, makes little allowance for modern developments. Nor is it flawless; in spite of the footnote appearing in Liepmann & Roshko's "Elements of Gasdynamics", and incidentally elaborated upon by Thompson, they pass on without comment Laplace's suggestion that a sound "wave propagates sufficiently fast to presume that the compression was isentropic" whereas, in reality, the changes in ordinary sound waves occur sufficiently slowly that the gradients so produced are small enough to render the isentropic assumption a good one. It contains much of the standard material in the subject and little that is not adequately described in existing books.

Reynolds, however, does adopt an interesting approach. In the first place he is not concerned merely with the dynamics of high-speed gases but, with the practising engineer in mind, in the thermodynamic and fluid mechanical aspects of processes in which "a flow of energy is associated with the fluid motion". Accordingly, he enriches his account by including a large number of illustrative examples whose variety is a particular attraction of the book. These examples alone serve to highlight the enormous range of problems that can confront the fluid-orientated engineer in the modern world. Thus amongst them are discussed a stream-generating nuclear-reactor, flow around an aircraft, a roller-gate for controlling heights of water levels, the bell-buoy and its associated three wave motions, the jet engine and many others. Second, Reynolds, almost throughout, uses what he calls "the one-dimensional flow model" or the "integral model of a flow" in which the fine detail of the motion is disregarded. Whilst acceptable in Engineering Departments (for whom, indeed, it is intended) because of the analytical simplifications thereby made possible, this restriction will probably prevent its adoption by others interested in rather more fundamental considerations. Nevertheless, such students could learn a great deal from the book both in the range and application of compressible fluid motions and the extensive use made of physical arguments.

Thompson, too, addressing a different audience, endeavours to add spice to the plain fare. Some of the ways by which this is achieved have already been mentioned; others include a final chapter on "Analogs in compressible flow" and a somewhat deeper excursion into physical acoustics. Furthermore, using Truesdell's historical articles as a source, he describes how key concepts were originally introduced (and the scepticism with which they were sometimes greeted!). This quickens the reader's interest and is not uninformative in itself. Thus, Thompson emphasizes fundamentals at the expense of applications which are limited "to those accessible to ordinary experience". In this sense it has a complementary rôle to that of the other undergraduate books in this list.

Finally, it is customary in consumer reports to indicate which brands represent value for money or even to recommend a 'best buy'. The last possibility is not appropriate for the books under review since, as has been shown, they do not all cater for the same public. However, Chapman & Walker and Reynolds are comparable and of the two Reynolds is to be preferred. In range, applicability and clarity it is superior and is recommended provided a treatment of such two-dimensional flows as Prandtl–Meyer flow or flow through an oblique shock are not required. Chapman & Walker do include these topics but in essence have provided yet another book little different from many that have appeared in the past; the feeling of *déjà-vu* comes through largely unrelieved. In the case of Thompson perhaps the best criterion is to compare it with a good established text covering the same field such as Liepmann & Roshko. Indeed, the author seems to have been strongly influenced by this book and acknowledges his debt to it in his preface. At the same time he has made an earnest attempt to make his book attractive and relevant to the seventies by pointing out modern trends in the subject and including a discussion of its relationship with overlapping disciplines. Whether these qualities justify the expenditure of the price of a new text book is best left to the prospective buyer. After all, Liepmann & Roshko is still available at £5.40.

A word should be added about Jaumotte, which contains a wealth of information on recent developments (with references up to 1970) in shock theory and experiment in the diverse fields to which reference has been made. It should prove invaluable to the research worker, actively engaged in the field, for the information it provides, to the commencing research student wishing to study shocks in gases (rarefied or not) or solids and looking for a source of material and to the teacher selecting material for a post-graduate course on shocks (provided that they read French). As a last thought the reviewer, along with some French fluid dynamicists whose help he solicited, remains baffled by the implied distinction in the title between shocks and shock waves.

R. J. GRIBBEN

Selected Writings of Hunter Rouse. Edited by J. F. KENNEDY and E. O. MACAGNO. Dover, 1972. 619 pp. $17.50.

Dr Hunter Rouse is retiring this year from the Deanery of the College of Engineering at the University of Iowa, Iowa City. To mark the occasion this volume has appeared, which reprints 57 of his published papers. The majority are concerned with fluid mechanics in a great variety of contexts. Most are in English, though there are contributions in German, Spanish and French. The last of these is unusual, for it is Rouse's doctoral thesis successfully submitted not long ago to the University of Paris; it might well have borne the sub-title 'An example of the influence of taxation upon academic activities'. In addition, a page of Japanese is thrown in for good measure.

Although these papers were produced over a period of 40 years, it must not be thought that they form a dry-as-dust collection of no consequence today. They include, for example, the work on cavitation in submerged jets which showed that in the search for quietness a change from screw to jet propulsion of ships may be disappointing. Again, his experiments on conduit expansions disclosed that the fluctuations in water pressure could be very considerable. His remark that they might be dangerous to the structure has since been strikingly confirmed by difficulties with a high-speed water tunnel. By no means all the papers deal with strictly scientific matters. There is a pleasing account of a night shift at a big hydraulics experimental station, and the pronunciation of the name Froude is considered at some length – a bold, not to say a rash undertaking for a citizen of the United States. Rouse's historical interests are shown by his account of the relationship between Johann Bernoulli and his son Daniel. Towards the end there are a few papers on engineering education, which reflect Rouse's decanal labours of recent years. As an epilogue the editors, forgetting Aesop's fable about the fisherman and his pipe, have inserted a discussion of a sociological topic.

Apart from minor corrections by the author, the papers appear unchanged from their original form. All have been expanded or reduced photographically to a page size $8\frac{1}{8}$ by 11 in., although the periodicals in which they first appeared vary greatly in dimensions. The *Journal of the Hydraulics Division of the*

American Society of Civil Engineers measures only $5\frac{1}{2}$ by $8\frac{1}{2}$ in., whereas *La Houille Blanche* is $8\frac{5}{8}$ by $11\frac{5}{8}$ in. Nevertheless, the result is entirely satisfactory. Indeed, the method is to be preferred to the alternative of resetting the text and redrawing the figures to give perfect uniformity throughout; exact references to the originals can be given at once, the price is prevented from rising out of reach, and further errors cannot creep in.

The book is furnished at the beginning with a biographical sketch and at the end with a complete list of publications classified under the headings books, booklets, and so forth. A consecutive system of numbering has been added throughout the book at the foot of the pages.

A. M. BINNIE

Theory of Viscoelasticity: an Introduction. By R. M. CHRISTENSEN. Academic Press, 1971. 245 pp. £6.30.

Although the study of viscoelasticity can be traced back to the nineteenth century, the greatest development has taken place in the last decade. There is therefore a need for an introduction to the subject which takes account of this recent work, and it is this need that the book under review attempts to meet.

The first chapter treats the constitutive equations of viscoelasticity. A number of equivalent formulations of these equations are possible. The author adopts the one most frequently employed at the present time, namely the expression of the components of stress as a function or functional of the past and current values of the components of strain. With this approach the relaxation functions represent the mechanical properties of the material. It is then shown how these functions are related to the creep functions, the differential operator forms of the constitutive equations and to the complex moduli.

The second chapter is devoted to isothermal boundary-value problems. In both this chapter and chapter 4, the author uses the word 'isothermal' in dynamic situations were this reviewer would prefer 'mechanical', because mechanical–thermal interaction is not included. In elasticity the mechanical theory is in fact the isentropic appoximation, which is valid except at very high frequencies, when the thermal interaction cannot be neglected because it produces high attentuation. After a uniqueness theorem for isothermal situations, chapter 2 treats cases in which the variables are separable. It then proceeds to deal with problems solvable by either Laplace or Fourier transforms combined with a correspondence principle. The examples solved include the torsional oscillation of a right circular cylinder, a cylinder under internal pressure, free vibration problems and indentation of a half-space.

Chapter 3 is entitled "Thermoviscoelasticity". The constitutive equations with thermal terms included are derived from an energy balance equation and the so-called Clausius–Dehem inequality. Provided one accepts the existence of an entropy function for irreversible processes, this is an excellent account. The temperature dependence of mechanical properties for actual materials is treated and an example given. Chapter 4 treats "Wave Propagation". In the first three sections there is only one independent space variable and the propagation of discontinuities, waves in a finite length rod, shear flow, and harmonic thermoviscoelastic waves are treated. Later sections consider the reflexion of harmonic waves at a plane boundary and moving loads on a half-space.

Chapter 5 is concerned with the extensions to viscoelasticity of the general theorems of elasticity, such as uniqueness and variational and minimum theorems. Chapter 6 is based upon the development of Coleman and his co-workers of a general thermodynamical theory of nonlinear viscoelasticity. Some knowledge of functional analysis is needed to understand this chapter. It includes two examples, simple shear of a solid and shear flow of a liquid. Chapter 7 is concerned with the experimental determination of the functions which represent the mechanical properties of viscoelastic materials. The principal procedures for linear materials are critically examined and typical results shown. The experimental verification of whether or not a particular material is thermo-rheologically simple is explained and illustrated. Finally, the difficulties of determining nonlinear properties are discussed.

Many references are given at the end of each chapter. As a guide and a source of references for the teacher this book serves a useful purpose. However, as an introduction for the student it has limitations. The author tends to state the governing equations and to plunge into the mathematical details of a complicated problem rather than first treating a simpler illustrative example. The text is not easy to follow, e.g. what does this sentence, which starts the section on dynamic response problems, mean: "In addition to problems of the type just discussed, another class of practical problems is that of the propagation of disturbances in bodies of finite extent with regard to the coordinate directions in which the field variables are not constant"? On page 123 the stress σ_{xy} as a function of time is stated to be given by an increasing staircase-type function, but it is plotted on the accompanying figure as a straight line parallel to the time axis. There are also examples of bad sentence construction which render understanding more difficult.

The above criticisms do not apply to those chapters which concern topics on which the author has himself researched; here the writing is probably as clear as the complexity of the subject matter permits. Elsewhere this reviewer feels that the author has selected almost at random a few relevant papers and then summarized the mathematical content for his examples. If only the author had laid aside all references and then developed his own account *ab initio*, he would have written a book which would have fulfilled the need described in the first paragraph. A thorough revision for a second edition could still do so.

D. R. BLAND

An Introduction to Turbulence and its Measurement. BY P. BRADSHAW. Pergamon, 1971. 218 pp. £2.50.

For many years turbulence has played a strangely elusive role in fluid mechanics. Although generally recognized as the central problem of the field, turbulence has been notably absent from most textbooks, undergraduate curricula, and the repertoire of most practising fluid dynamicists. This mysterious elusiveness, plus a notorious capacity for making pursuers that try to get too close vanish, may well have inspired the amusing chapter headings from Lewis Carroll's *The Hunting of the Snark: an Agony in Eight Fits.*

It is clear that a major factor contributing to the obscurity of turbulence has been the scarcity of readable books on the subject at an introductory level. Those unwilling to push through mathematical thickets of Fourier Stieltjes integrals bristling with tensor indices have been effectively denied entree. The major positive contribution of the present book should be to ease the pain of the initiation ceremonies for those who have no other choice but to face up to a problem in turbulence and wish to get familiar with the vocabulary, the physical principles, and especially the measurement techniques.

The author wisely begins with a glossary of terms, like "eddy" and "decibel", peculiar to turbulence and electronics. He then proceeds with a very attenuated discussion of the physics of turbulence, a review of the most important measurable statistical parameters (except structure functions) and some examples of important turbulent flows. The remainder (over half) is devoted to measurement techniques, the hot-wire anemometer, data analysis, temperature and concentration measurement, and a summary of practical details, with appendices on the equations of motion and turbulence research. Little attempt is made to discuss historic developments, or to document the description of turbulence or measurement techniques with references to the literature. References are given primarily to extend, not support, the material presented: a slightly authoritarian style common in textbooks having the distinct advantage of conciseness.

It seems unfair to criticize such a book for any omissions, since even the mildest tendency toward completion would have expanded the volume dramatically. It does seem that some mention of the physics of turbulent mixing might have been included to complement the chapter on temperature and concentration measurements. The mean temperature equation was included in the appendix, but the physical significance of the temperature dissipation term as a rate of entropy production similar to the velocity dissipation was obscurred by contrasting the two, and no mention was made of the existence of universal similarity laws of scalar mixing. In fact, although Kolmogoroff's universal similarity laws for turbulent velocity are used implicitly, and effectively, thoughout the text, an explicit statement is not given. Probably it is wise to isolate beginners in turbulence from the mathematicians as long as possible, but excluding Kolmogoroff and the rest of the Russian school from the "References" and "Further Reading" does seem to be overdoing it.

A chapter devoted to examples of turbulent flows effectively illustrates a wide variety of important turbulence phenomena. It is refreshing to read an introductory account which neither begins nor relies on mixing lengths and eddy viscosities to describe turbulence, and furthermore gives an example and physical explanation of a case where the eddy viscosity is negative. Some important features of atmospheric and oceanic turbulence are discussed, and even non-Newtonian turbulence is mentioned.

The discussion of measurement techniques and the hot-wire anemometer will be extremely valuable to beginners, and even some "experts", since it is repleat with the wisdom of long association with a difficult specialty. Hot-wire anemometer probe construction is in danger of becoming a lost art in these days when competing manufacturers sell them off the shelf, and many of the limitations and pitfalls of their use might be overlooked because they are so easy to get. Repeated emphasis is given to the importance of direct calibration in the flow system conditions if not the flow system itself, before, during, and after the measurement. Some of the more exotic measurement techniques are pointed out, and the use of laser Doppler velocimetry put in prospective. Every opportunity is taken to relate the discussion to real measurement problems, for instance by including sample calculations for a typical hot wire used under specific conditions so that the scaling laws given permit ready extrapolation to the reader's own application.

The subject of turbulence data analysis is developing very rapidly, which may account for the fact that some of the information given in this section is now questionable. The discussion begins with the premise that digital recording and processing will be prohibitively expensive for most turbulence research projects. At one time this was true, but it is certainly not now. Large general purpose computers costing 3 cents/s can transform and average 10^3 to 10^4 samples/s compared to a cost of \$2.40/10^4 samples cited. Smaller specialized computers can be just as fast and cost one or two orders of magnitude less. Statements that digital computers are fundamentally inefficient to calculate mean-square or even mean values are questionable, despite the fact that the calculation may involve 10^5 numbers: as indicated, this may only cost a fraction of a cent, and most probably will be included free with a menagerie of much more interesting statistics.

Since most analog projects can now be done just as cheaply with digital techniques and since digital processing is vastly more flexible, accurate and rapid, the implication that turbulence research still must be done with analog instrumentation is very misleading in this reviewer's opinion.

Although computers may take over more and more of the task, analog devices will always be involved, and these too have been in a state of rapid development. Nowadays it is not necessary to pay "hundreds" of pounds for a single quadrant multiplier when integrated-circuit four-quadrant multipliers are available for less than one. Cheap operational amplifier modules make it unnecessary to redesign d.c. amplifiers around transistor characteristics.

For a variety of reasons including funding, many readers either will not be in a position to take full advantage of the latest developments in computers and circuity, or may wish to get started with old reliable equipment. In such cases, the present book gives just the sort of guidance most fluid dynamicists will want and be able to understand.

To summarize, this should be a very popular and useful book, especially for beginning turbulence experimenters. It also contains a wealth of practical information, interesting ideas on turbulence research philosophy and clear discussions of the physics of a variety of important turbulent flows, so that most specialists in turbulence will benefit, and probably enjoy reading it as well.

C. H. Gibson