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LECTURES IN APPLIED MATHEMATICS

VOLUME III

PARTIAL DIFFERENTIAL EQUATIONS

by LIPMAN BERS, FRITZ JOHN, and MARTIN SCHECHTER,
all of the Courant Institute of Mathematical Sciences, New York University

With Special Lectures by
Lars Garding
A. N. Milgram

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Partial Differential Equations Lectures In Applied Mathematics Volume 3

Richard von Mises,Kurt O. Friedrichs

Partial Differential Equations Lectures In Applied Mathematics Volume 3:

Trends and Perspectives in Applied Mathematics Lawrence Sirovich,2012-12-06 This marks the 100th volume to appear in the Applied Mathematical Sci ences series Partial Differential Equations by Fritz John the first volume of the series appeared in 1971 One year prior to its appearance the then mathematics editor of Springer Verlag Klaus Peters organized a meeting to look into the possibility of starting a series slanted toward applications The meeting took place in New Rochelle at the home of Fritz and Char lotte John K O Friedrichs Peter Lax Monroe Donsker Joe Keller and others from the Courant Institute previously the Institute for Mathemat ical Sciences were present as were Joe LaSalle and myself the two of us having traveled down from Providence for the meeting The John home a large comfortable house especially lent itself to the informal relaxed and wide ranging discussion that ensued What emerged was a consensus that mathematical applications appeared to be poised for a period of growth and that there was a clear need for a series committed to applied mathematics The first paragraph ofthe editorial statement written at that time reads as follows The mathematization of all sciences the fading of traditional scientific boundaries the impact of computer technology the growing importance of mathematical computer modeling and the necessity of scientific planning all create the need both in education and research for books that are introductory to and abreast of these developments *Proceedings of the Summer Seminar, Boulder. Colorado. 1957. Lectures in Applied Mathematics. Vol. 3. Partial Differential Equations* Lipman Bers,Fritz John,Martin Schechter,Lars Gårding,A. N. Milgram,1964 Fluid Dynamics Richard von Mises,Kurt O. Friedrichs,2012-12-06 In the summer of 1941 Brown University undertook a Program of Advanced Instruction and Research in Mechanics This in fact was the precursor to the present day Division of Applied Mathematics Certainly an outstanding feature of this program must have been the lectures in Fluid Dynamics by Professor Friedrichs and the late Professor von Mises Their notes were prepared in mimeograph form and given a wide distribution at that time Since their appearance these lectures have had a strong influence on teaching and research in the subject As the reader soon learns the notes have lost none of their vitality over the years Indeed in certain instances only in the last few years has the field caught up with the ideas developed in the course of these lectures Many ideas of value are still to be found in these notes and the Editors are most happy to be able to include this volume in the series The corrections which have accumulated over the years have been incorporated and in addition an index has been added With these exceptions all desire to revise has been resisted Also in this connection we are very grateful to Dr T H Chong for carefully overseeing the preparation of the present manuscript Semidynamical Systems in Infinite Dimensional Spaces Stephen H. Saperstone,2012-12-06 Where do solutions go and how do they behave en route These are two of the major questions addressed by the qualita tive theory of differential equations The purpose of this book is to answer these questions for certain classes of equa tions by recourse to the framework of semidynamical systems or topological dynamics as it is sometimes called This approach makes it possible to treat a seemingly broad range of equations from nonautonomous ordinary differential equa tions and partial differential equations to stochastic differ ential equations The methods are not limited to the examples presented here though The basic idea is this Embed some representation of the solutions of the equation and perhaps the equation itself in an appropriate function space This space serves as the phase space for the semidynamical system The phase map must be chosen so as to generate solutions to the equation from an initial value In most instances it is necessary to provide a weak topology on the phase space Typically the space is infinite dimensional These considerations motivate the requirement to study semidynamical systems in non locally compact spaces Our objective here is to present only those results needed for the kinds of applications one is likely to encounter in differen tial equations Additional properties and extensions of ab stract semidynamical systems are left as exercises The power of the semidynamical framework makes it possible to character Preface ize the asymptotic behavior of the solutions of such a wide class of equations **Inviscid Fluid Flows** Hilary Ockendon,Alan B. Tayler,2013-11-21 Applied Mathematics is the art of constructing mathematical models of observed phenomena so that both qualitative and quantitative results can be predicted by the use of analytical and numerical methods Theoretical Mechanics is concerned with the study of those phenomena which can be ob served in everyday life in the physical world around us It is often characterised by the macroscopic approach which allows the concept of an element or particle of material small compared to the dimensions of the phenomena being modelled yet large compared to the molecular size of the material Then atomic and molecular phenomena appear only as quantities averaged over many molecules It is therefore natural that the mathemati cal models derived are in terms of functions which are continuous and well behaved and that the analytical and numerical methods required for their development are strongly dependent on the theory of partial and ordinary differential equations Much pure research in Mathematics has been stimu lated by the need to develop models of real situations and experimental observations have often led to important conjectures and theorems in Analysis It is therefore important to present a careful account of both the physical or experimental observations and the mathematical analysis used The authors believe that Fluid Mechanics offers a rich field for il lustrating the art of mathematical modelling the power of mathematical analysis and the stimulus of applications to readily observed phenomena Solution of Variational Inequalities in Mechanics Ivan Hlavacek,Jaroslav Haslinger,Jindrich Necas,Jan Lovisek,2012-12-06 The idea for this book was developed in the seminar on problems of con tinuum mechanics which has been active for more than twelve years at the Faculty of Mathematics and Physics Charles University Prague This seminar has been pursuing recent directions in the development of mathe matical applications in physics especially in continuum mechanics and in technology It has regularly been attended by upper division and graduate students faculty and scientists and researchers from various institutions from Prague and elsewhere These seminar participants decided to publish in a self contained monograph the results of their individual and collective efforts in developing applications for the theory of variational inequalities which is currently a rapidly growing branch of modern analysis The theory of variational inequalities is a relatively young mathematical discipline Apparently one of the main bases for its development was the paper by G Fichera 1964 on the solution of the Signorini problem in the theory of elasticity Later J L Lions and G Stampacchia 1967 laid the foundations of the theory itself Time dependent inequalities have primarily been treated in works of J L Lions and H Bnlzis The diverse applications of the variational in equalities theory are the topics of the well known monograph by G Du vaut and J L Lions Les iniquations en micanique et en physique 1972 **Linear Optimization and Approximation** K. Glashoff,S.-A. Gustafson,2012-12-06 A linear optimization problem is the task of minimizing a linear real valued function of finitely many variables subject to linear con straints in general there may be infinitely many constraints This book is devoted to such problems Their mathematical properties are investi gated and algorithms for their computational solution are presented Applications are discussed in detail Linear optimization problems are encountered in many areas of appli cations They have therefore been subject to mathematical analysis for a long time We mention here only two classical topics from this area the so called uniform approximation of functions which was used as a mathematical tool by Chebyshev in 1853 when he set out to design a crane and the theory of systems of linear inequalities which has already been studied by Fourier in 1823 We will not treat the historical development of the theory of linear optimization in detail However we point out that the decisive break through occurred in the middle of this century It was urged on by the need to solve complicated decision problems where the optimal deployment of military and civilian resources had to be determined The availability of electronic computers also played an important role The principal computational scheme for the solution of linear optimization problems the simplex algorithm was established by Dantzig about 1950 In addi tion the fundamental theorems on such problems were rapidly developed based on earlier published results on the properties of systems of linear inequalities **Stochastic Processes** J. Lamperti,2012-12-06 This book is the result of lectures which I gave dur ing the academic year 1972 73 to third year students a Aarhus University in Denmark The purpose of the book as of the lectures is to survey some of the main themes in the modern theory of stochastic processes In my previous book Probability survey of the mathe matical theory I gave a short overview of classical proba bility mathematics concentrating especially on sums of inde pendent random variables I did not discuss specific appli cations of the theory I did strive for a spirit friendly to application by coming to grips as fast as I could with the major problems and techniques and by avoiding too high levels of abstraction and completeness At the same time I tried to make the proofs both rigorous and motivated and to show how certain results have evolved rather than just presenting them in polished final form The same remarks apply to this book at least as a statement of intentions and it can serve as a sequel to the earlier one continuing the story in the same style and spirit The contents of the present book fall roughly into two parts The first deals mostly with stationary processes which provide the mathematics for describing phenomena in a steady state overall but subject to random fluctuations Chapter 4 is the heart of this part Integral Transforms and their Applications B. Davies,2013-11-11 In preparing this second edition I have restricted myself to making small corrections and changes to the first edition Two chapters have had extensive changes made First the material of Sections 14 1 and 14 2 has been rewritten to make explicit reference to the book of Bleistein and Handelsman which appeared after the original Chapter 14 had been written Second Chapter 21 on numerical methods has been rewritten to take account of comparative work which was done by the author and Brian Martin and published as a review paper The material for all of these chapters was in fact prepared for a transla tion of the book Considerable thought has been given to a much more com prehensive revision and expansion of the book In particular there have been spectacular advances in the solution of some non linear problems using isospectra1 methods which may be re garded as a generalization of the Fourier transform However the subject is a large one and even a modest introduction would have added substantially to the book Moreover the recent book by Dodd et al is at a similar level to the present volume Similarly I have refrained from expanding the chapter on num erical methods into a complete new part of the book since a specialized monograph on numerical methods is in preparation in collaboration with a colleague An Introduction to Infinite Dimensional Dynamical Systems - Geometric Theory J.K. Hale,L.T. Magalhaes,W.M. Oliva,2013-04-17 Including An Introduction to the Homotopy Theory in Noncompact Spaces **Compressible Fluid Flow and Systems of Conservation Laws in Several Space Variables** A. Majda,2012-12-06 Conservation laws arise from the modeling of physical processes through the following three steps 1 The appropriate physical balance laws are derived for m phy t cal quantities ul with u ul u and u x t defined m for x xl E RN N 1 2 or 3 t 0 and with the values m u x t lying in an open subset G of R the state space The state space G arises because physical quantities such as the density or total energy should always be positive thus the values of u are often con strained to an open set G 2 The flux functions appearing in these balance laws are idealized through prescribed nonlinear functions F u mapping G into J j 1 N while source terms are defined by S u x t with S a given smooth function of these arguments with values in Rm In parti lar the detailed microscopic effects of diffusion and dissipation are ignored 3 A generalized version of the principle of virtual work is applied see Antman 1 The formal result of applying the three steps 1 3 is that the m physical quantities u define a weak solution of an m x m system of conservation laws o I N Wt u r W F u W S u x t dxdt 1 1 R xR j l Xj J for all W E C RN x R W x t E Rm **Nonlinear Singular Perturbation Phenomena** K. W. Chang,F. A. Howes,2012-12-06 Our purpose in writing this monograph is twofold On the one hand we want to collect in one place many of the recent results on the exist ence and asymptotic behavior of solutions of certain classes of singularly perturbed nonlinear boundary value problems On the other we hope to raise along the way a number of questions for further study mostly ques tions we ourselves are unable to answer The presentation involves a study of both scalar and vector boundary value problems for ordinary dif ferential equations by means of the consistent use of differential in equality techniques Our results for scalar boundary value problems obeying some type of maximum principle are fairly complete however we have been unable to treat under any circumstances problems involving resonant behavior The linear theory for such problems is incredibly complicated already and at the present time there appears to be little hope for any kind of general nonlinear theory Our results for vector boundary value problems even those admitting higher dimensional maximum principles in the form of invariant regions are also far from complete We offer them with some trepidation in the hope that they may stimulate further work in this challenging and important area of differential equa tions The research summarized here has been made possible by the support over the years of the National Science Foundation and the National Science and Engineering Research Council Operational Calculus Kosaku Yosida,2012-12-06 In the end of the last century Oliver Heaviside inaugurated an operational calculus in connection with his researches in electromagnetic theory In his operational calculus the operator of differentiation was denoted by the symbol p The explanation of this operator p as given by him was difficult to understand and to use and the range of the valid ity of his calculus remains unclear still now although it was widely noticed that his calculus gives correct results in general In the 1930s Gustav Doetsch and many other mathematicians began to strive for the mathematical foundation of Heaviside s operational calculus by virtue of the Laplace transform pt e f t dt However the use of such integrals naturally confronts restrictions con cerning the growth behavior of the numerical function f t as t At about the midcentury Jan Mikusinski invented the theory of con volution quotients based upon the Titchmarsh convolution theorem If f t and get are continuous functions defined on O such that the convolution f f t u g u du 0 then either f t 0 or get 0 must hold The convolution quotients include the operator of differentiation s and related operators Mikusinski s operational calculus gives a satisfactory basis of Heaviside s operational calculus it can be applied successfully to linear ordinary differential equations with constant coefficients as well as to the telegraph equation which includes both the wave and heat equa tions with constant coefficients **Sound Propagation in Stratified Fluids** Calvin H. Wilcox,2012-12-06 Stratified fluids whose densities sound speeds and other parameters are functions of a single depth coordinate occur widely in nature Indeed the earth s gravitational field imposes a stratification on its atmosphere oceans and lakes It is well known that their stratification has a profound effect on the propagation of sound in these fluids The most striking effect is probably the occurrence of acoustic ducts due to minima of the sound speed that can trap sound waves and cause them to propagate hori zontally The reflection transmission and distortion of sonar signals by acoustic ducts is important in interpreting sonar echoes Signal scattering by layers of microscopic marine organisms is important to both sonar engi neers and marine biologists Again reflection of signals from bottom sediment layers overlying a penetrable bottom are of interest both as sources of unwanted echoes and in the acoustic probing of such layers Many other examples could be given The purpose of this monograph is to develop from first principles a theory of sound propagation in stratified fluids whose densities and sound speeds are essentially arbitrary functions of the depth In physical terms the propagation of both time harmonic and transient fields is analyzed The corresponding mathematical model leads to the study of boundary value problems for a scalar wave equation whose coefficients contain the pre scribed density and sound speed functions Scattering Theory for Diffraction

Gratings Calvin H. Wilcox,2012-12-06 The scattering of acoustic and electromagnetic waves by periodic sur faces plays a role in many areas of applied physics and engineering Opti cal diffraction gratings date from the nineteenth century and are still widely used by spectroscopists More recently diffraction gratings have been used as coupling devices for optical waveguides Trains of surface waves on the oceans are natural diffraction gratings which influence the scattering of electromagnetic waves and underwater sound Similarly the surface of a crystal acts as a diffraction grating for the scattering of atomic beams This list of natural and artificial diffraction gratings could easily be extended The purpose of this monograph is to develop from first principles a theory of the scattering of acoustic and electromagnetic waves by periodic surfaces In physical terms the scattering of both time harmonic and transient fields is analyzed The corresponding mathematical model leads to the study of boundary value problems for the Helmholtz and d Alembert wave equations in plane domains bounded by periodic curves In the formal ism adopted here these problems are intimately related to the spectral analysis of the Laplace operator acting in a Hilbert space of functions defined in the domain adjacent to the grating **Regular and Stochastic Motion** A. J. Lichtenberg,M. A. Lieberman,2013-03-14 This book treats stochastic motion in nonlinear oscillator systems It describes a rapidly growing field of nonlinear mechanics with applications to a number of areas in science and engineering including astronomy plasma physics statistical mechanics and hydrodynamics The main em phasis is on intrinsic stochasticity in Hamiltonian systems where the stochastic motion is generated by the dynamics itself and not by external noise However the effects of noise in modifying the intrinsic motion are also considered A thorough introduction to chaotic motion in dissipative systems is given in the final chapter Although the roots of the field are old dating back to the last century when Poincare and others attempted to formulate a theory for nonlinear perturbations of planetary orbits it was new mathematical results obtained in the 1960 s together with computational results obtained using high speed computers that facilitated our new treatment of the subject Since the new methods partly originated in mathematical advances there have been two or three mathematical monographs exposing these developments However these monographs employ methods and language that are not readily accessible to scientists and engineers and also do not give explicit tech niques for making practical calculations In our treatment of the material we emphasize physical insight rather than mathematical rigor We present practical methods for describing the motion for determining the transition from regular to stochastic behavior and for characterizing the stochasticity We rely heavily on numerical computations to illustrate the methods and to validate them **The Stability and Control of Discrete Processes** J.P. LaSalle,2012-12-06 Professor J P LaSalle died on July 7 1983 at the age of 67 The present book is being published posthumously with the careful assistance of Kenneth Meyer one of the students of Professor LaSalle It is appropriate that the last publi cation of Professor LaSalle should be on a subject which con tains many interesting ideas is very useful in applications and can be understood at an undergraduate level In addition to making many significant contributions at the research level to differential equations and control theory he was an excel lent teacher and had the ability to make sophisticated con cepts appear to be very elementary Two examples of this are his books with N Hasser and J Sullivan on analysis published by Ginn and Co 1949 and 1964 and the book with S Lefschetz on stability by Liapunov s second method published by Academic Press 1961 Thus it is very fitting that the present volume could be completed Jack K Hale Kenneth R Meyer TABLE OF CONTENTS page 1 Introduction 1 2 Liapunov s direct method 7 3 Linear systems Xl Ax 13 4 An algorithm for computing An 19 5 Acharacterization of stable matrices Computational criteria 24 6 Liapunovls characterization of stable matrices A Liapunov function for Xl Ax 32 7 Stability by the linear approximation 38 8 The general solution of Xl Ax The Jordan Canonical Form 40 9 Higher order equations The general solution of z y O

Asymptotic Methods for Relaxation Oscillations and Applications Johan Grasman,2012-12-06 In various fields of science notably in physics and biology one is con fronted with periodic phenomena having a remarkable temporal structure it is as if certain systems are periodically reset in an initial state A paper of Van der Pol in the Philosophical Magazine of 1926 started up the investigation of this highly nonlinear type of oscillation for which Van der Pol coined the name relaxation oscillation The study of relaxation oscillations requires a mathematical analysis which differs strongly from the well known theory of almost linear oscillations In this monograph the method of matched asymptotic expansions is employed to approximate the periodic orbit of a relaxation oscillator As an introduction in chapter 2 the asymptotic analysis of Van der Pol s equation is carried out in all detail The problem exhibits all features characteristic for a relaxation oscillation From this case study one may learn how to handle other or more generally formulated relaxation oscillations In the survey special attention is given to biological and chemical relaxation oscillators In chapter 2 a general definition of a relaxation oscillation is formulated **Theoretical Approaches to Turbulence** D.L. Dwoyer,M.Y. Hussaini,R.G. Voigt,2012-12-06 Turbulence is the lIDst natural nDde of fluid lIDtion and has been the subject of scientific study for all Dst a century During this period various ideas and techniques have evolved to nDdel turbulence Following Saffman these theoretical approaches can be broadly divided into four overlapping categories 1 analytical lIDdelling 2 physical lIDdelling 3 phenomenologicalllDdelling and 4 nurerical lIDdelling With the purpose of stmtnarizing our ent understanding of these theoretical approaches to turbulence recognized leaders fluid dynamicists mathematicians and physicists in the field were invited to participate in a formal workshop during October 10 12 1984 sponsored by The Institute for CooIputer Applications in Science and Engineering and NASA Langley Research Center Kraiciman McCcxnb Pouquet and Spiegel represented the category of analytical nDdelling while Landahl and Saffman represented physical lIDdelling The contributions of Latmder and Spalding were in the category of phenanenological lIDdelling and those of Ferziger and Reynolds in the area of nurericalllDdelling Aref Cholet Lumley Moin Pope and Temam served on the panel discussions With the care and cooperation of the participants the workshop achieved its purpose and we believe that its proceedings published in this vol llre has lasting scientific value The tone of the workshop was set by two introductory talks by Bushnell and ChaImm Buslmell presented the engineering viewpoint while Chapman reviewed from a historical perspective developments in the study of turbulence The remaining talks dealt with specific aspects of the theoretical approaches to fluid turbulence **Averaging Methods in Nonlinear Dynamical Systems** Jan A. Sanders,Ferdinand Verhulst,2013-04-17 In this book we have developed the asymptotic analysis of nonlinear dynamical systems We have collected a large number of results scattered throughout the literature and presented them in a way to illustrate both the underlying common theme as well as the diversity of problems and solutions While most of the results are known in the literature we added new material which we hope will also be of interest to the specialists in this field The basic theory is discussed in chapters two and three Improved results are obtained in chapter four in the case of stable limit sets In chapter five we treat averaging over several angles here the theory is less standardized and even in our simplified approach we encounter many open problems Chapter six deals with the definition of normal form After making the somewhat philosophical point as to what the right definition should look like we derive the second order normal form in the Hamiltonian case using the classical method of generating functions In chapter seven we treat Hamiltonian systems The resonances in two degrees of freedom are almost completely analyzed while we give a survey of results obtained for three degrees of freedom systems The appendices contain a mix of elementary results expansions on the theory and research problems

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