

Symmetry Properties and Exact Solutions of the Fokker-Planck Equation

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Abstract

Symmetry properties of some Fokker-Planck equations are studied. In the one-dimensional case, when symmetry groups turn out to be six-parameter ones, this allows to find changes of variables to reduce such Fokker-Planck equations to the one-dimensional heat equation. The symmetry and the family of exact solutions of the Kramers equation are obtained.

The one-dimensional Fokker-Planck (FP) equation has the form

$$\frac{\partial u}{\partial t} = -\frac{\partial}{\partial x} [A(x, t)u] + \frac{1}{2} \frac{\partial^2}{\partial x^2} [B(x, t)u], \quad (1)$$

where $u = u(x, t)$ is the probability density; A and B are differentiable functions. This is the basic equation in the theory of continuous Markovian processes. The following FP equations are of special interest [1, 2]:

(a) diffusion in a gravitational field

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial x} (gu) + \frac{1}{2} D \frac{\partial^2 u}{\partial x^2}, \quad (2)$$

(b) the Ornstein-Uhlenbeck process

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial x} (kxu) + \frac{1}{2} D \frac{\partial^2 u}{\partial x^2}, \quad (3)$$

(c) the Rayleigh-type process

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial x} \left[\left(\gamma x - \frac{\mu}{x} \right) u \right] + \frac{1}{2} \mu \frac{\partial^2 u}{\partial x^2}, \quad (4)$$

(d) models in population genetics [2]

$$\frac{\partial u}{\partial t} = \frac{\alpha}{2} \frac{\partial^2}{\partial x^2} [(x-c)^2 u] + \beta \frac{\partial}{\partial x} [(x-c)u], \quad (5)$$

$$\frac{\partial u}{\partial t} = \frac{\partial^2}{\partial x^2} [(1-x^2)^2 u], \quad (6)$$

$$\frac{\partial u}{\partial t} = \frac{\alpha}{2} \frac{\partial^2}{\partial x^2} [x^2 (1-x^2)^2 u], \quad (7)$$

Symmetry Analysis And Exact Solutions Of Equations Of Nonlinear Mathematical Physics

Jérémie Unterberger, Claude Roger



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Symmetry Analysis and Exact Solutions of Equations of Nonlinear Mathematical Physics W. I. Fushchich, W. M. Shtelen, N. I. Serov, 2014-01-15 Symmetry Analysis and Exact Solutions of Equations of Nonlinear Mathematical Physics Vil'gel'm Il'ich Fushchich, Vladimir Mikhaïlovich Shtelen', Nikolaï Ivanovich Serov, 1993-02-28 This volume presents an account of the current state of algebraic theoretic methods as applied to linear and nonlinear multidimensional equations of mathematical and theoretical physics Equations are considered that are invariant under Euclid Galilei Schrödinger Poincaré conformal and some other Lie groups with special emphasis being given to the construction of wide classes of exact solutions of concrete nonlinear partial differential equations such as d'Alembert Liouville Monge Ampère Hamilton Jacobi eikonal Schrödinger Navier Stokes gas dynamics Dirac Maxwell Dirac Yang Mills etc Ansatz for spinor as well as scalar and vector fields are described and formulae for generating solutions via conformal transformations are found explicitly for scalar spinor vector and tensor fields with arbitrary conformal degree The classical three body problem is considered for the group theoretic point of view The symmetry of integro differential equations is also studied and the method of finding final nonlocal transformations is described Furthermore the concept of conditional symmetry is introduced and is used to obtain new non Lie Ansatz for nonlinear heat and acoustic equations The volume comprises an Introduction which presents a brief account of the main ideas followed by five chapters appendices and a comprehensive bibliography This book will be of interest to researchers and graduate students in physics and mathematics interested in algebraic theoretic methods in mathematical and theoretical physics **CRC Handbook of Lie Group Analysis of Differential Equations** Nail H. Ibragimov, 1995-10-24 Today Lie group theoretical approach to differential equations has been extended to new situations and has become applicable to the majority of equations that frequently occur in applied sciences Newly developed theoretical and computational methods are awaiting application Students and applied scientists are expected to understand these methods Volume 3 and the accompanying software allow readers to extend their knowledge of computational algebra Written by the world's leading experts in the field this up to date sourcebook covers topics such as Lie-Bäcklund conditional and non classical symmetries approximate symmetry groups for equations with a small parameter group analysis of differential equations with distributions integro differential equations recursions and symbolic software packages The text provides an ideal introduction to modern group analysis and addresses issues to both beginners and experienced researchers in the application of Lie group methods **CRC Handbook of Lie Group Analysis of Differential Equations, Volume III** Nail H. Ibragimov, 2024-11-01 Today Lie group theoretical approach to differential equations has been extended to new situations and has become applicable to the majority of equations that frequently occur in applied sciences Newly developed theoretical and computational methods are awaiting application Students and applied scientists are expected to understand these methods Volume 3 and the accompanying software allow readers to extend their knowledge of computational algebra Written

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Nonlinear Symmetries and Nonlinear Equations G. Gaeta, 2012-12-06 The study of nonlinear differential equations was S Lie's motivation when he created what is now known as Lie groups and Lie algebras nevertheless although Lie group and algebra theory flourished and was applied to a number of different physical situations up to the point that a lot if not most of current fundamental elementary particles physics is actually physical interpretation of group theory the application of symmetry methods to differential equations remained a sleeping beauty for many many years The main reason for this lies probably in a fact that is quite clear to any beginner in the field Namely the formidable complexity of the algebraic not numerical computations involved in Lie method I think this does not account completely for this oblivion in other fields of Physics very hard analytical computations have been worked through anyway one easily understands that systems of dozens of coupled PDEs do not seem very attractive nor a very practical computational tool

Lie and non-Lie Symmetries: Theory and Applications for Solving Nonlinear Models Roman M.

Cherniha, 2018-07-06 This book is a printed edition of the Special Issue Lie Theory and Its Applications that was published in Symmetry

Applications of Symmetry Methods to Partial Differential Equations George W. Bluman, Alexei F.

Cheviakov, Stephen Anco, 2009-10-30 This is an accessible book on the advanced symmetry methods for differential equations including such subjects as conservation laws Lie B cklund symmetries contact transformations adjoint symmetries Nther's Theorem mappings with some modification potential symmetries nonlocal symmetries nonlocal mappings and non classical method Of use to graduate students and researchers in mathematics and physics

Symmetry and Exact Solutions of Nonlinear Mathematical Physics Equations Gangwei Wang, Xiangpeng Xin, Samir A. El-Tantawy, 2024-08-13 Nonlinear problems originating from applied science that is closely related to practices contain rich and extensive content It makes the corresponding nonlinear models also complex and diverse Due to the intricacy and contingency of nonlinear problems unified mathematical methods still remain far and few between In this regard the comprehensive use of symmetric methods along with other mathematical methods becomes an effective option to solve nonlinear problems

Lie Symmetry Analysis of Fractional Differential Equations Mir Sajjad Hashemi, Dumitru Baleanu, 2020-07-09 The trajectory of fractional calculus has undergone several periods of intensive development both in pure and applied sciences During the last few decades fractional calculus has also been associated with the power law effects and its various applications It is a natural to ask if fractional calculus as a nonlocal calculus can produce new results within the well established field of Lie symmetries and their applications In Lie Symmetry Analysis of Fractional Differential Equations the authors try to answer this vital question

by analyzing different aspects of fractional Lie symmetries and related conservation laws Finding the exact solutions of a given fractional partial differential equation is not an easy task but is one that the authors seek to grapple with here The book also includes generalization of Lie symmetries for fractional integro differential equations Features Provides a solid basis for understanding fractional calculus before going on to explore in detail Lie Symmetries and their applications Useful for PhD and postdoc graduates as well as for all mathematicians and applied researchers who use the powerful concept of Lie symmetries Filled with various examples to aid understanding of the topics [Handbook of Nonlinear Partial Differential Equations](#) Andrei D. Polyanin,Valentin F. Zaitsev,2004-06-02 The Handbook of Nonlinear Partial Differential Equations is the latest in a series of acclaimed handbooks by these authors and presents exact solutions of more than 1600 nonlinear equations encountered in science and engineering many more than any other book available The equations include those of parabolic hyperbolic elliptic and other types and the authors pay special attention to equations of general form that involve arbitrary functions A supplement at the end of the book discusses the classical and new methods for constructing exact solutions to nonlinear equations To accommodate different mathematical backgrounds the authors avoid wherever possible the use of special terminology outline some of the methods in a schematic simplified manner and arrange the equations in increasing order of complexity Highlights of the Handbook

Nonlinear Systems and Their Remarkable Mathematical Structures Norbert Euler,Maria Clara Nucci,2019-12-06 Nonlinear Systems and Their Remarkable Mathematical Structures Volume 2 is written in a careful pedagogical manner by experts from the field of nonlinear differential equations and nonlinear dynamical systems both continuous and discrete This book aims to clearly illustrate the mathematical theories of nonlinear systems and its progress to both non experts and active researchers in this area Just like the first volume this book is suitable for graduate students in mathematics applied mathematics and engineering sciences as well as for researchers in the subject of differential equations and dynamical systems Features Collects contributions on recent advances in the subject of nonlinear systems Aims to make the advanced mathematical methods accessible to the non experts Suitable for a broad readership including researchers and graduate students in mathematics and applied mathematics

The Schrödinger-Virasoro Algebra Jérémie Unterberger,Claude Roger,2011-10-25 This monograph provides the first up to date and self contained presentation of a recently discovered mathematical structure the Schrödinger Virasoro algebra Just as Poincaré invariance or conformal Virasoro invariance play a key role in understanding respectively elementary particles and two dimensional equilibrium statistical physics this algebra of non relativistic conformal symmetries may be expected to apply itself naturally to the study of some models of non equilibrium statistical physics or more specifically in the context of recent developments related to the non relativistic AdS/CFT correspondence The study of the structure of this infinite dimensional Lie algebra touches upon topics as various as statistical physics vertex algebras Poisson geometry integrable systems and supergeometry as well as representation theory the cohomology of infinite dimensional Lie algebras and the

spectral theory of Schrödinger operators **Journal of Nonlinear Mathematical Physics Vol. 14** , *Functional Analysis and its Applications* Vladimir Kadets, Wiesław Tadeusz Zelazko, 2004-07-31 The conference took place in Lviv Ukraine and was dedicated to a famous Polish mathematician Stefan Banach the most outstanding representative of the Lviv mathematical school Banach spaces introduced by Stefan Banach at the beginning of twentieth century are familiar now to every mathematician The book contains a short historical article and scientific contributions of the conference participants mostly in the areas of functional analysis general topology operator theory and related topics *Symmetries in Fundamental Physics* Kurt Sundermeyer, 2014-07-23 Over the course of the last century it has become clear that both elementary particle physics and relativity theories are based on the notion of symmetries These symmetries become manifest in that the laws of nature are invariant under spacetime transformations and or gauge transformations The consequences of these symmetries were analyzed as early as in 1918 by Emmy Noether on the level of action functionals Her work did not receive due recognition for nearly half a century but can today be understood as a recurring theme in classical mechanics electrodynamics and special relativity Yang Mills type quantum field theories and in general relativity As a matter of fact as shown in this monograph many aspects of physics can be derived solely from symmetry considerations This substantiates the statement of E P Wigner if we knew all the laws of nature or the ultimate Law of nature the invariance properties of these laws would not furnish us new information Thanks to Wigner we now also understand the implications of quantum physics and symmetry considerations Poincaré invariance dictates both the characteristic properties of particles mass spin and the wave equations of spin 0 1 2 1 objects Further the work of C N Yang and R Mills reveals the consequences of internal symmetries as exemplified in the symmetry group of elementary particle physics Given this pivotal role of symmetries it is thus not surprising that current research in fundamental physics is to a great degree motivated and inspired by considerations of symmetry The treatment of symmetries in this monograph ranges from classical physics to now well established theories of fundamental interactions to the latest research on unified theories and quantum gravity **Applied Analysis in Biological and Physical Sciences** Jim M. Cushing, M. Saleem, H. M. Srivastava, Mumtaz Ahmad Khan, M. Merajuddin, 2016-12-01 The book contains recent developments and contemporary research in mathematical analysis and in its application to problems arising from the biological and physical sciences The book is of interest to readers who wish to learn of new research in such topics as linear and nonlinear analysis mathematical biology and ecology dynamical systems graph theory variational analysis and inequalities functional analysis differential and difference equations partial differential equations approximation theory and chaos All papers were prepared by participants at the International Conference on Recent Advances in Mathematical Biology Analysis and Applications ICMBAA 2015 held during 4-6 June 2015 in Aligarh India A focal theme of the conference was the application of mathematics to the biological sciences and on current research in areas of theoretical mathematical analysis that can be used as sophisticated tools for the study of scientific problems The

conference provided researchers academicians and engineers with a platform that encouraged them to exchange their innovative ideas in mathematical analysis and its applications as well as to form interdisciplinary collaborations The content of the book is divided into three parts Part I contains contributions from participants whose topics are related to nonlinear dynamics and its applications in biological sciences Part II has contributions which concern topics on nonlinear analysis and its applications to a variety of problems in science engineering and industry Part III consists of contributions dealing with some problems in applied analysis

Fractional Differential Equations Anatoly Kochubei, Yuri Luchko, 2019-02-19 This multi volume handbook is the most up to date and comprehensive reference work in the field of fractional calculus and its numerous applications This second volume collects authoritative chapters covering the mathematical theory of fractional calculus including ordinary and partial differential equations of fractional order inverse problems and evolution equations

Homotopy-Based Methods in Water Engineering Manotosh Kumbhakar, Vijay P. Singh, 2023-07-20 Most complex physical phenomena can be described by nonlinear equations specifically differential equations In water engineering nonlinear differential equations play a vital role in modeling physical processes Analytical solutions to strong nonlinear problems are not easily tractable and existing techniques are problem specific and applicable for specific types of equations Exploring the concept of homotopy from topology different kinds of homotopy based methods have been proposed for analytically solving nonlinear differential equations given by approximate series solutions Homotopy Based Methods in Water Engineering attempts to present the wide applicability of these methods to water engineering problems It solves all kinds of nonlinear equations namely algebraic transcendental equations ordinary differential equations ODEs systems of ODEs partial differential equations PDEs systems of PDEs and integro differential equations using the homotopy based methods The content of the book deals with some selected problems of hydraulics of open channel flow with or without sediment transport groundwater hydrology surface water hydrology general Burger s equation and water quality Features Provides analytical treatments to some key problems in water engineering Describes the applicability of homotopy based methods for solving nonlinear equations particularly differential equations Compares different approaches in dealing with issues of nonlinearity

Chaos, Solitons, and Fractals , 1995 **Integral Methods in Science and Engineering** Christian Constanda, Jukka Saranen, S Seikkala, 2020-01-16 Based on proceedings of the International Conference on Integral Methods in Science and Engineering this collection of papers addresses the solution of mathematical problems by integral methods in conjunction with approximation schemes from various physical domains Topics and applications include wavelet expansions reaction diffusion systems variational methods fracture theory boundary value problems at resonance micromechanics fluid mechanics combustion problems nonlinear problems elasticity theory and plates and shells Volume 1 covers Analytic Methods

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