

# MARKOV SEMIGROUPS AND GROUPS OF OPERATORS

JERÓNIMO A. GOLDSTEIN, ROSA MARIA MENINZI, AND SILVIA ROMANELLI

**ABSTRACT.** We consider different realizations of the operators  $L_{\theta,a} u(x) := x^{2a} u''(x) + (ax^{2a-1} + \theta x^a) u'(x)$ ,  $\theta \in \mathbb{R}$ ,  $a \in \mathbb{R}$ , acting on suitable spaces of real valued continuous functions. The main results deal with the existence of Feller semigroups generated by  $L_{\theta,a}$  and the representation  $L_{\theta,a} = G_a^2 + \theta G_a$ , where  $G_a u = x^a u'$ ,  $0 \leq a \leq 1$ , generates a (not necessarily strongly continuous) group. Explicit formulas of the generated semigroups are also deduced.

## 1. Introduction

Let us denote by  $C(\overline{J})$  the space of all real valued continuous functions on an interval  $J$ , having finite limits at all endpoints not included in  $J$ , equipped with the sup-norm.

We are interested in the operators

$$L_{\theta,a} u(x) := x^{2a} u''(x) + (ax^{2a-1} + \theta x^a) u'(x),$$

where  $\theta \in \mathbb{R}$ ,  $a \in \mathbb{R}$ .

In [7], using Feller classification of the boundary points we showed that for any  $\theta \in \mathbb{R}$ ,  $a \in \mathbb{R}$ , the operator  $L_{\theta,a}$  generates a Feller semigroup on  $C[0, +\infty]$ . Here, in addition to analogous generation results in different spaces of continuous functions, we obtain an explicit representation of the semigroup generated by  $L_{\theta,a}$  for suitable  $a$ . Indeed, if  $0 \leq a \leq 1$  and  $G_a u := x^a u'$ , then the operator  $L_{\theta,a}$  can be represented as

$$L_{\theta,a} u = G_a^2 u + \theta G_a u,$$

where  $G_a$  generates a (not necessarily strongly continuous) group. Thus a variant of Romanov's formula applies and the results follow. For the connections with the Black-Merton-Scholes equation see [8].

In the following, for any Banach space  $X$ ,  $C(\mathbb{R}, X)$  will denote the Banach space of all  $X$ -valued continuous functions defined in  $\mathbb{R}$  and  $\mathcal{L}_K(X)$  the Banach algebra of all linear bounded operators on a Banach space  $X$  over  $K$ , for  $K = \mathbb{R}$  or  $K = \mathbb{C}$ .

## 2. Feller semigroups, analytic semigroups and cosine functions

This section provides a brief description of the basic definitions and results about Feller semigroups, analytic semigroups and cosine functions, which form a functional analytic background for our results.

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2000 *Mathematics Subject Classification.* Primary 47D00; Secondary 47D06, 47D07.  
*Key words and phrases.* Markov semigroups, operator semigroups and groups.

# Schrodinger Operators Markov Semigroups Wavelet Analysis Operator Algebras Advances In Partial Differential Equations

**Francis Nier, Bernard Helffer**



## **Schrodinger Operators Markov Semigroups Wavelet Analysis Operator Algebras Advances In Partial Differential Equations:**

Schrödinger Operators, Markov Semigroups, Wavelet Analysis, Operator Algebras Michael Demuth, 1996 The analysis of partial differential equations has stimulated large areas of research in mathematical physics harmonic analysis and operator theory The present volume illuminates the depth and variety of these interactions It begins with a survey on the use of semiclassical analysis and maximum principle techniques in statistical mechanics There follows an article presenting the perturbation theory for generators of Markov semigroups acting on  $L_p$  The third contribution provides a self contained introduction to continuous wavelet analysis including its relations to function spaces and microlocal regularity this is particularly topical as wavelet methods have been applied with great success in the past decade to problems in harmonic and numerical analysis as well as in diverse fields of engineering The final section explores pseudo differential analysis on singular configurations with special emphasis on  $C$  algebra techniques Mellin operators and analytical index formulas

Schrödinger Operators, Markov Semigroups, Wavelet Analysis, Operator Algebras Michael Demuth, Elmar Schrohe, Bert-Wolfgang Schulze, Johannes Sjöstrand, 1996-09-26 The analysis of partial differential equations has stimulated large areas of research in mathematical physics harmonic analysis and operator theory The present volume illuminates the depth and variety of these interactions It begins with a survey on the use of semiclassical analysis and maximum principle techniques in statistical mechanics There follows an article presenting the perturbation theory for generators of Markov semigroups acting on  $L_p$  The third contribution provides a self contained introduction to continuous wavelet analysis including its relations to function spaces and microlocal regularity this is particularly topical as wavelet methods have been applied with great success in the past decade to problems in harmonic and numerical analysis as well as in diverse fields of engineering The final section explores pseudo differential analysis on singular configurations with special emphasis on  $C$  algebra techniques Mellin operators and analytical index formulas

**Microlocal Analysis and Spectral Theory** Luigi Rodino, 2012-12-06 The NATO Advanced Study Institute Microlocal Analysis and Spectral Theory was held in Tuscany Italy at Castelvecchio Pascoli in the district of Lucca hosted by the international vacation center 11 Ciocco from September 23 to October 3 1996 The Institute recorded the considerable progress realized recently in the field of Microlocal Analysis In a broad sense Microlocal Analysis is the modern version of the classical Fourier technique in solving partial differential equations where now the localization proceeding takes place with respect to the dual variables too Precisely through the tools of pseudo differential operators wave front sets and Fourier integral operators the general theory of the linear partial differential equations is now reaching a mature form in the frame of Schwartz distributions or other generalized functions At the same time Microlocal Analysis has grown up into a definite and independent part of Mathematical Analysis with other applications all around Mathematics and Physics one major theme being Spectral Theory for Schrodinger equation in

Quantum Mechanics

### **Hypoelliptic Estimates and Spectral Theory for Fokker-Planck Operators and Witten Laplacians**

Francis Nier, Bernard Helffer, 2005-01-17 There has recently been a renewal of interest in Fokker Planck operators motivated by problems in statistical physics in kinetic equations and differential geometry Compared to more standard problems in the spectral theory of partial differential operators those operators are not self adjoint and only hypoelliptic The aim of the analysis is to give as generally as possible an accurate qualitative and quantitative description of the exponential return to the thermodynamical equilibrium While exploring and improving recent results in this direction this volume proposes a review of known techniques on the hypoellipticity of polynomial of vector fields and its global counterpart the global Weyl H rmander pseudo differential calculus the spectral theory of non self adjoint operators the semi classical analysis of Schr dinger type operators the Witten complexes and the Morse inequalities *Elliptic Mixed, Transmission and Singular Crack Problems* Gohar Harutyunyan, Bert-Wolfgang Schulze, 2007 Mixed transmission or crack problems belong to the analysis of boundary value problems on manifolds with singularities The Zaremba problem with a jump between Dirichlet and Neumann conditions along an interface on the boundary is a classical example The central theme of this book is to study mixed problems in standard Sobolev spaces as well as in weighted edge spaces where the interfaces are interpreted as edges Parametrices and regularity of solutions are obtained within a systematic calculus of boundary value problems on manifolds with conical or edge singularities This calculus allows singularities on the interface and homotopies between mixed and crack problems Additional edge conditions are computed in terms of relative index results In a detailed final chapter the intuitive ideas of the approach are illustrated and there is a discussion of future challenges A special feature of the text is the inclusion of many worked out examples which help the reader to appreciate the scope of the theory and to treat new cases of practical interest This book is addressed to mathematicians and physicists interested in models with singularities associated boundary value problems and their solvability strategies based on pseudo differential operators The material is also useful for students in higher semesters and young researchers as well as for experienced specialists working in analysis on manifolds with geometric singularities the applications of index theory and spectral theory operator algebras with symbolic structures quantisation and asymptotic analysis **Semiclassical Analysis, Witten Laplacians, And Statistical Mechanics**

Bernard Helffer, 2002-09-10 This important book explains how the technique of Witten Laplacians may be useful in statistical mechanics It considers the problem of analyzing the decay of correlations after presenting its origin in statistical mechanics In addition it compares the Witten Laplacian approach with other techniques such as the transfer matrix approach and its semiclassical analysis The author concludes by providing a complete proof of the uniform Log Sobolev inequality

**Approaches to Singular Analysis** Juan B. Gil, 2001-03 This collection presents various approaches to analytic problems that arise in the context of singular spaces It contains articles offering introductions to various pseudodifferential calculi and discussions of relations between them plus invited papers from mathematicians who have made significant contributions to

this field     *Spectral Theory, Microlocal Analysis, Singular Manifolds* Michael Demuth,1997     **Mathematical Reviews**,2005     **Boundary Value Problems and Singular Pseudo-Differential Operators** Bert-Wolfgang Schulze,1998-02-04

With this volume Wolfgang Schulze presents a study of pseudo differential operators on singular spaces and also of developments of the concept of ellipticity in operator algebra     **The Cauchy Problem for Hyperbolic Operators** Karen Yagdjian,1997     **Max-Planck-Gesellschaft Jahrbuch** ,1997     Subject Guide to Books in Print ,1991     J.C.

*Poggendorffs biographisch-literarisches Handwörterbuch zur Geschichte der exacten Wissenschaften ...* Johann Christian Poggendorff,1999     **Annales de l'Institut Fourier** Institut Fourier,1949     Satzungen und Mitgliederverzeichnis Gesellschaft für Angewandte Mathematik und Mechanik,1998     **Operator Semigroups Meet Complex Analysis, Harmonic Analysis and Mathematical Physics** Wolfgang Arendt,Ralph Chill,Yuri Tomilov,2015-12-10

This proceedings volume originates from a conference held in Herrnhut in June 2013 It provides unique insights into the power of abstract methods and techniques in dealing successfully with numerous applications stemming from classical analysis and mathematical physics The book features diverse topics in the area of operator semigroups including partial differential equations martingale and Hilbert transforms Banach and von Neumann algebras Schrödinger operators maximal regularity and Fourier multipliers interpolation operator theoretical problems concerning generation perturbation and dilation for example and various qualitative and quantitative Tauberian theorems with a focus on transfinite induction and magics of Cantor The last fifteen years have seen the dawn of a new era for semigroup theory with the emphasis on applications of abstract results often unexpected and far removed from traditional ones The aim of the conference was to bring together prominent experts in the field of modern semigroup theory harmonic analysis complex analysis and mathematical physics and to present the lively interactions between all of those areas and beyond In addition the meeting honored the sixtieth anniversary of Prof C J K Batty whose scientific achievements are an impressive illustration of the conference goal These proceedings present contributions by prominent scientists at this international conference which became a landmark event They will be a valuable and inspiring source of information for graduate students and established researchers     **Partial Differential Operators and Mathematical Physics** Michael Demuth,Bert-Wolfgang Schulze,1995-05-01     **Semigroups of Operators -Theory and Applications** Jacek Banasiak,Adam Bobrowski,Mirosław Lachowicz,2014-11-20

Many results both from semi group theory itself and from the applied sciences are phrased in discipline specific languages and hence are hardly known to a broader community This volume contains a selection of lectures presented at a conference that was organised as a forum for all mathematicians using semi group theory to learn what is happening outside their own field of research The collection will help to establish a number of new links between various sub disciplines of semigroup theory stochastic processes differential equations and the applied fields The theory of semigroups of operators is a well developed branch of functional analysis Its foundations were laid at the beginning of the 20th century while the fundamental generation

theorem of Hille and Yosida dates back to the forties The theory was from the very beginning designed as a universal language for partial differential equations and stochastic processes but at the same time it started to live as an independent branch of operator theory Nowadays it still has the same distinctive flavour it develops rapidly by posing new internal questions and in answering them discovering new methods that can be used in applications On the other hand it is influenced by questions from PDEs and stochastic processes as well as from applied sciences such as mathematical biology and optimal control and thus it continually gathers a new momentum Researchers and postgraduate students working in operator theory partial differential equations probability and stochastic processes analytical methods in biology and other natural sciences optimization and optimal control will find this volume useful

**Operator Theory, Pseudo-Differential Equations, and Mathematical Physics** Yuri I. Karlovich, Luigi Rodino, Bernd Silberman, Ilya M. Spitkovsky, 2012-10-30 This volume is a collection of papers devoted to the 70th birthday of Professor Vladimir Rabinovich The opening article by Stefan Samko includes a short biography of Vladimir Rabinovich along with some personal recollections and bibliography of his work It is followed by twenty research and survey papers in various branches of analysis pseudodifferential operators and partial differential equations Toeplitz Hankel and convolution type operators variable Lebesgue spaces etc close to Professor Rabinovich's research interests Many of them are written by participants of the International workshop Analysis Operator Theory and Mathematical Physics Ixtapa Mexico January 23-27 2012 having a long history of scientific collaboration with Vladimir Rabinovich and are partially based on the talks presented there The volume will be of great interest to researchers and graduate students in differential equations operator theory functional and harmonic analysis and mathematical physics

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