

# A KAM-THEOREM FOR EQUATIONS OF THE KORTEWEG – DE VRIES TYPE

SERGEI B. KUKSIN

**ABSTRACT.** We study quasilinear Hamiltonian partial differential equations with one-dimensional space variable in a segment of real line. We assume that the equation has a family of  $n$ -frequency time-quasiperiodic solutions, depending on an  $n$ -dimensional amplitude vector, and prove that most of these solutions persist under Hamiltonian perturbations of the equation by a nonlinear term which contains less derivatives than the linear part of the unperturbed equation. The result is similar to one proved in [K] for perturbations which contain no derivatives.

## Introduction

In this paper we are concerned with quasilinear Hamiltonian partial differential equations with nonlinearities depending on derivatives. We study the equations which are close to a linear equation or to an integrable one. As good examples, let us consider the perturbed Korteweg-de Vries (KdV) equation

$$(1) \quad \dot{u}(t, x) = \frac{\partial}{\partial x} (-u_{xx} + 6u^2 + \varepsilon^2 f(u, x)), \quad x \in S^1 = \mathbb{R}/2\pi \mathbb{Z},$$

and a perturbation of the linear equation, similar to KdV:

$$(2) \quad \dot{u}(t, x) = \frac{\partial}{\partial x} (-u_{xx} + V(x)u + \varepsilon f(u, x)), \quad x \in S^1.$$

Both (1) and (2) become infinite-dimensional Hamiltonian systems if we consider them as dynamical systems in a space of periodic functions  $\{u(x)\}$  with zero mean value:

$$(3) \quad \int_0^{2\pi} u \, dx = 0.$$

This restriction is correct for both equations since for their solutions the mean values in  $x$  are time-independent quantities.

Consider the differential operator

$$(4) \quad u(x) \longmapsto \frac{\partial}{\partial x} (-u_{xx} + V(x)u)$$

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# Kam Theorem For Equations Of The Kortevegde Vries Type

**Shasha Hu**



### **Kam Theorem For Equations Of The Korteweg de Vries Type:**

**KdV & KAM** Thomas Kappeler, Jürgen Pöschel, 2003-05-19 This text treats the Korteweg de Vries KdV equation with periodic boundary conditions This equation models waves in homogeneous weakly nonlinear and weakly dispersive media in general For the first time these important results are comprehensively covered in book form authored by internationally renowned experts in the field     A KAM Theorem for Equations of the Korteweg-de Vries Type Raymond Bonnett, 1998-06-01

**Geometric Analysis and Nonlinear Partial Differential Equations** Stefan Hildebrandt, Hermann Karcher, 2012-12-06 This book is not a textbook but rather a coherent collection of papers from the field of partial differential equations Nevertheless we believe that it may very well serve as a good introduction into some topics of this classical field of analysis which despite of its long history is highly modern and well prospering Richard Courant wrote in 1950 It has always been a temptation for mathematicians to present the crystallized product of their thought as a deductive general theory and to relegate the individual mathematical phenomenon into the role of an example The reader who submits to the dogmatic form will be easily indoctrinated Enlightenment however must come from an understanding of motives live mathematical development springs from specific natural problems which can be easily understood but whose solutions are difficult and demand new methods or more general significance We think that many if not all papers of this book are written in this spirit and will give the reader access to an important branch of analysis by exhibiting interesting problems worth to be studied Most of the collected articles have an extensive introductory part describing the history of the presented problems as well as the state of the art and offer a well chosen guide to the literature This way the papers became lengthier than customary these days but the level of presentation is such that an advanced graduate student should find the various articles both readable and stimulating

**Handbook of Dynamical Systems** A. Katok, B. Hasselblatt, 2005-12-17 This second half of Volume 1 of this Handbook follows Volume 1A which was published in 2002 The contents of these two tightly integrated parts taken together come close to a realization of the program formulated in the introductory survey Principal Structures of Volume 1A The present volume contains surveys on subjects in four areas of dynamical systems Hyperbolic dynamics parabolic dynamics ergodic theory and infinite dimensional dynamical systems partial differential equations Written by experts in the field The coverage of ergodic theory in these two parts of Volume 1 is considerably more broad and thorough than that provided in other existing sources The final cluster of chapters discusses partial differential equations from the point of view of dynamical systems

**Perturbation Theory** Giuseppe Gaeta, 2022-12-16 This volume in the Encyclopedia of Complexity and Systems Science Second Edition is devoted to the fundamentals of Perturbation Theory PT as well as key applications areas such as Classical and Quantum Mechanics Celestial Mechanics and Molecular Dynamics Less traditional fields of application such as Biological Evolution are also discussed Leading scientists in each area of the field provide a comprehensive picture of the landscape and the state of the art with the specific goal of combining mathematical rigor

explicit computational methods and relevance to concrete applications New to this edition are chapters on Water Waves Rogue Waves Multiple Scales methods legged locomotion Condensed Matter among others while all other contributions have been revised and updated Coverage includes the theory of Poincare Birkhoff Normal Forms aspects of PT in specific mathematical settings Hamiltonian KAM theory Nekhoroshev theory and symmetric systems technical problems arising in PT with solutions convergence of series expansions diagrammatic methods parametric resonance systems with nilpotent real part PT for non smooth systems and on PT for PDEs write out this acronym partial differential equations Another group of papers is focused specifically on applications to Celestial Mechanics Quantum Mechanics and the related semiclassical PT Quantum Bifurcations Molecular Dynamics the so called choreographies in the N body problem as well as Evolutionary Theory Overall this unique volume serves to demonstrate the wide utility of PT while creating a foundation for innovations from a new generation of graduate students and professionals in Physics Mathematics Mechanics Engineering and the Biological Sciences

Hamiltonian Dynamical Systems and Applications Walter Craig, 2008-02-17 This volume is the collected and extended notes from the lectures on Hamiltonian dynamical systems and their applications that were given at the NATO Advanced Study Institute in Montreal in 2007 Many aspects of the modern theory of the subject were covered at this event including low dimensional problems Applications are also presented to several important areas of research including problems in classical mechanics continuum mechanics and partial differential equations

*Analysis of Hamiltonian PDEs* Sergej B. Kuksin, 2000 For the last 20 30 years interest among mathematicians and physicists in infinite dimensional Hamiltonian systems and Hamiltonian partial differential equations has been growing strongly and many papers and a number of books have been written on integrable Hamiltonian PDEs During the last decade though the interest has shifted steadily towards non integrable Hamiltonian PDEs Here not algebra but analysis and symplectic geometry are the appropriate analysing tools The present book is the first one to use this approach to Hamiltonian PDEs and present a complete proof of the KAM for PDEs theorem It will be an invaluable source of information for postgraduate mathematics and physics students and researchers

*Dynamical Systems and Small Divisors* Hakan Eliasson, Stefano Marmi, Sergei Kuksin, Jean-Christophe Yoccoz, 2004-10-11 Many problems of stability in the theory of dynamical systems face the difficulty of small divisors The most famous example is probably given by Kolmogorov Arnold Moser theory in the context of Hamiltonian systems with many applications to physics and astronomy Other natural small divisor problems arise considering circle diffeomorphisms or quasiperiodic Schroedinger operators In this volume Hakan Eliasson Sergei Kuksin and Jean Christophe Yoccoz illustrate the most recent developments of this theory both in finite and infinite dimension A list of open problems including some problems contributed by John Mather and Michel Herman has been included

**European Congress of Mathematics** Antal Balog, Domokos Szasz, András Recski, Gyula O.H. Katona, 2012-12-06 This is the second volume of the proceedings of the second European Congress of Mathematics Volume I presents the speeches delivered at the

Congress the list of lectures and short summaries of the achievements of the prize winners Together with volume II it contains a collection of contributions by the invited lecturers Finally volume II also presents reports on some of the Round Table discussions This two volume set thus gives an overview of the state of the art in many fields of mathematics and is therefore of interest to every professional mathematician Contributors Vol I N Alon L Ambrosio K Astala R Benedetti Ch Bessenrodt F Bethuel P Bj rstad E Bolthausen J Bricmont A Kupiainen D Burago L Caporaso U Dierkes I Dynnikov L H Eliasson W T Gowers H Hedenmalm A Huber J Kaczorowski J Koll r D O Kramkov A N Shiryaev C Lescop R M rz Vol II J Matousek D McDuff A S Merkurjev V Milman St M ller T Nowicki E Olivieri E Scoppola V P Platonov J P schel L Polterovich L Pyber N Sim nyi J P Solovej A Stipsicz G Tardos J P Tignol A P Veselov E Zuazua *Quasi-Periodic Traveling Waves on an Infinitely Deep Perfect Fluid Under Gravity* Roberto Feola,Filippo Giuliani,2024-04-17 View the abstract *Atti Del ... Congresso Internazionale Dei Matematici ...* ,1998 **Encyclopaedia of Mathematics** Michiel Hazewinkel,2013-12-01 This ENCYCLOPAEDIA OF MATHEMATICS aims to be a reference work for all parts of mathe matics It is a translation with updates and editorial comments of the Soviet Mathematical Encyclopaedia published by Soviet Encyclopaedia Publishing House in five volumes in 1977 1985 The annotated translation consists of ten volumes including a special index volume There are three kinds of articles in this ENCYCLOPAEDIA First of all there are survey type articles dealing with the various main directions in mathematics where a rather fine subdivi sion has been used The main requirement for these articles has been that they should give a reasonably complete up to date account of the current state of affairs in these areas and that they should be maximally accessible On the whole these articles should be understandable to mathematics students in their first specialization years to graduates from other mathematical areas and depending on the specific subject to specialists in other domains of science en gineers and teachers of mathematics These articles treat their material at a fairly general level and aim to give an idea of the kind of problems techniques and concepts involved in the area in question They also contain background and motivation rather than precise statements of precise theorems with detailed definitions and technical details on how to carry out proofs and constructions The second kind of article of medium length contains more detailed concrete problems results and techniques **Mathematical Reviews** ,2007 *Invariant Manifolds and Fibrations for Perturbed Nonlinear Schrödinger Equations* Charles Li,Stephen Wiggins,2012-12-06 This book presents a development of invariant manifold theory for a spe cific canonical nonlinear wave system the perturbed nonlinear Schrooinger equation The main results fall into two parts The first part is concerned with the persistence and smoothness of locally invariant manifolds The sec ond part is concerned with fibrations of the stable and unstable manifolds of inflowing and overflowing invariant manifolds The central technique for proving these results is Hadamard s graph transform method generalized to an infinite dimensional setting However our setting is somewhat different than other approaches to infinite dimensional invariant manifolds since for conservative wave equations many of the interesting invariant manifolds are infinite dimensional and

noncompact The style of the book is that of providing very detailed proofs of theorems for a specific infinite dimensional dynamical system the perturbed nonlinear Schrodinger equation The book is organized as follows Chapter one gives an introduction which surveys the state of the art of invariant manifold theory for infinite dimensional dynamical systems Chapter two develops the general setup for the perturbed nonlinear Schrodinger equation Chapter three gives the proofs of the main results on persistence and smoothness of invariant manifolds Chapter four gives the proofs of the main results on persistence and smoothness of fibrations of invariant manifolds This book is an outgrowth of our work over the past nine years concerning homoclinic chaos in the perturbed nonlinear Schrodinger equation The theorems in this book provide key building blocks for much of that work *Hamiltonian Systems and Fourier Analysis* Daniel Benest, Claude Froeschlé, Elena Lega, 2005 Proceedings of the International Congress of Mathematicians: Invited lectures Gerd Fischer, Ulf Rehmann, 1998 **Nonlinear Dynamics** Muthusamy Lakshmanan, Shanmuganathan Rajaseekar, 2012-12-06 Integrability chaos and patterns are three of the most important concepts in nonlinear dynamics These are covered in this book from fundamentals to recent developments The book presents a self contained treatment of the subject to suit the needs of students teachers and researchers in physics mathematics engineering and applied sciences who wish to gain a broad knowledge of nonlinear dynamics It describes fundamental concepts theoretical procedures experimental and numerical techniques and technological applications of nonlinear dynamics Numerous examples and problems are included to facilitate the understanding of the concepts and procedures described In addition to 16 chapters of main material the book contains 10 appendices which present in depth mathematical formulations involved in the analysis of various nonlinear systems Reviews in Mathematics and Mathematical Physics, 1995 *Direct and Projective Limits of Geometric Banach Structures*. Patrick Cabau, Fernand Pelletier, 2023-10-06 This book describes in detail the basic context of the Banach setting and the most important Lie structures found in finite dimension The authors expose these concepts in the convenient framework which is a common context for projective and direct limits of Banach structures The book presents sufficient conditions under which these structures exist by passing to such limits In fact such limits appear naturally in many mathematical and physical domains Many examples in various fields illustrate the different concepts introduced Many geometric structures existing in the Banach setting are stable by passing to projective and direct limits with adequate conditions The convenient framework is used as a common context for such types of limits The contents of this book can be considered as an introduction to differential geometry in infinite dimension but also a way for new research topics This book allows the intended audience to understand the extension to the Banach framework of various topics in finite dimensional differential geometry and moreover the properties preserved by passing to projective and direct limits of such structures as a tool in different fields of research **Chaos** Angelo Vulpiani, 2010 Chaos from simple models to complex systems aims to guide science and engineering students through chaos and nonlinear dynamics from classical examples to the most recent

fields of research The first part intended for undergraduate and graduate students is a gentle and self contained introduction to the concepts and main tools for the characterization of deterministic chaotic systems with emphasis to statistical approaches The second part can be used as a reference by researchers as it focuses on more advanced topics including the characterization of chaos with tools of information theory and applications encompassing fluid and celestial mechanics chemistry and biology The book is novel in devoting attention to a few topics often overlooked in introductory textbooks and which are usually found only in advanced surveys such as information and algorithmic complexity theory applied to chaos and generalization of Lyapunov exponents to account for spatiotemporal and non infinitesimal perturbations The selection of topics numerous illustrations exercises and proposals for computer experiments make the book ideal for both introductory and advanced courses

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web mar 21 2023 correct answer a john steinbeck explanation of mice and men is a well known novella written by john steinbeck he is a renowned american author who is known for his realistic and socially conscious works his writing often explores themes of human nature social injustice and the struggles of the working class

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web of mice and men argues that on the bottom rung of the american economy the destitute are left with only stark and terrible choices why does lennie have a dead mouse in his pocket as the story begins lennie has a dead mouse in his pocket because he likes to pet soft things but doesn t know his own strength and accidentally killed the mouse

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web 5 read this extract and use it to answer questions 5 7 crooks the negro stable buck had his bunk in the harness room a little shed that leaned off the wall of the barn on one side of the

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web jan 23 2019 of mice and men quiz check your knowledge quiz of mice and men first edition whitmore rare books by quentin cohan updated on january 23 2019 1 which character shoots candy s old dog curley crooks george carlson carlson shoots candy s old dog he calls the dog decrepit and useless and says that he wants to put the dog

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web bored and restless dreams of being a hollywood star curley s wife prince of the ranch gives lennie a puppy slim true or false george s actions forced both men to leave their jobs in weed false true or false george and lennie are cousins false true or false lennie is completely dependent on george

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web 1 what did lennie forget in chapter one a why he and george had to run from their last job b how to tie his shoes c not to clutch mice so tightly d that george wasn t his cousin 2 what would aunt clara always give to lennie when he was little a chocolate b spankings c mice d lemon drops 3

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web your answer block please just type the number ex 4 5 your answer multiple choice the first setting in the novel is on the ranch in weed on the ranch in soledad in the barn in the brush

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web quick quizzes full book quiz 1 of 25 of mice and men was first published in what year 1919 1962 1937 1939 2 of 25 what

is the name of the town from which george and lennie are fleeing when the story opens weed soledad salinas the town is never named 3 of 25 what excites lennie most about his dream life with george he will learn to farm

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web why did steinbeck choose the title of mice and men what happened in weed why does carlson shoot candy s dog why does curley attack lennie why does george kill lennie why does lennie have a dead mouse in his pocket how is lennie different from the other men why do george and lennie travel together why does curley wear a glove on

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web of mice and men by john steinbeck is focused on the unlikely friendship of workers george and lennie will their friendship survive the harsh conditions they live in

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web of mice and men q explain and comment on the relationship between george and lennie a 1 george and lennie share a unique and special relationship 2 they are inseparable friends 3 george takes lennie as his responsibility and looks out for him 4 george is tough and smart while lennie is huge in size but childlike shy and timid 5

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web sep 15 2023 correct answer c john steinbeck explanation john steinbeck is the correct answer because he is the author of the novel of mice and men the book published in 1937 tells the story of two displaced ranch workers george and lennie during the great depression

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web mar 22 2023 this quiz will help test your knowledge and understanding of the characters in john steinbeck s novel of mice and men questions 10 attempts 1432 last updated mar 22 2023 sample question

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web lennie george question 2 of 7 who says guys like us that work on ranches are the loneliest guys in the world they got no family they don't belong no place with us it ain't

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