Some Perturbation Problems from Quantum Mechanics

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This time we shall discuss some probelms of time-independent perturbation in Qunatum Mehanics. We consider 'slightly modified' harmonic oscillators and find energy eigenvalues by perturbation method, and also by exact treatment, for comparison. The reader should not form the impression that it can be done with every problem! Indeed, parterbation method is an approximate method for solving problems which cannot be solved exactly. A careful study of these probelms will also help develop a good understanding of the use of ladder operators in Quantum Mechanics.

Q1 Consider a 1D harmonic oscillator with potential energy $V = \frac{1}{2}(1 + \epsilon)kx^2$, where k, ϵ are constants. (a) Find the expression for exact energy eigenvalues. Expand an arbitrary eigenvalue in a power series in ϵ upto to second power. (b) Now obtain the energy eigenvalues by treating the term $\frac{1}{2}\epsilon kx^2 = \epsilon V$ as a small perturbation (i.e, $\epsilon \ll 1$, and dimensionless). Show that the perturbation calculations give the same results as the exact treatment of part (a) upto second order in ϵ.

Solution

(a) We shall assume the solution for the standard 1D harmonic oscillator with potential energy term $V = \frac{1}{2}kx^2$, where k is the spring constant. As we know, the energy eigenvalues for this oscillator are given by $E_n = (n + \frac{1}{2})\hbar\omega$, with $n = 0, 1, 2, \ldots$, $\omega = \sqrt{k/m}$, m being the mass. And if we take the given potential $V = \frac{1}{2}(1 + \epsilon)kx^2$, we can readily give it the standard form by simply setting $k' = (1 + \epsilon)k$, as ϵ is a constant. In this case we have the energy eigenvalues $E'_n = (n + \frac{1}{2})\hbar\omega'$, $\omega' = \sqrt{k'/m} = \sqrt{(1 + \epsilon)k/m} = \sqrt{(1 + \epsilon)}\omega$. Thus we have $E'_n = \sqrt{(1 + \epsilon)}E_n$. For $\epsilon < 1$ we expand this in powers of ϵ (Mclaurin series) as

$$E'_n = \left[1 + \frac{1}{2}\epsilon - \frac{1}{8}\epsilon^2 + \ldots\right]E_n$$
$$= E_n + \frac{1}{2}\epsilon E_n - \frac{1}{8}\epsilon^2 E_n + \ldots \quad [1]$$

(b) The Hamiltonian in this case is

$$H = \frac{p^2}{2m} + \frac{1}{2}kx^2 + \frac{1}{2}k\epsilon x^2$$
$$= H_0 + H' \quad [2]$$

Where $H_0 = \frac{p^2}{2m} + \frac{1}{2}kx^2$ is the unperturbed Hamiltonian and $H' = \frac{1}{2}k\epsilon x^2$ is the perturbation term, with $\epsilon \ll 1$. The first order correction E_n^1 to the unperturbed enrgy E_n is given by (note E_n^1 is different

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M Gitterman

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A First Look at Perturbation Theory James G. Simmonds,James E. Mann, Jr.,1998-01-01 Undergraduates in engineering and the physical sciences receive a thorough introduction to perturbation theory in this useful and accessible text Students discover methods for obtaining an approximate solution of a mathematical problem by exploiting the presence of a small dimensionless parameter the smaller the parameter the more accurate the approximate solution Knowledge of perturbation theory offers a twofold benefit approximate solutions often reveal the exact solution s essential dependence on specified parameters also some problems resistant to numerical solutions may yield to perturbation methods In fact numerical and perturbation methods can be combined in a complementary way The text opens with a well defined treatment of finding the roots of polynomials whose coefficients contain a small parameter Proceeding to differential equations the authors explain many techniques for handling perturbations that reorder the equations or involve an unbounded independent variable Two disparate practical problems that can be solved efficiently with perturbation methods conclude the volume Written in an informal style that moves from specific examples to general principles this elementary text emphasizes the why along with the how prerequisites include a knowledge of one variable calculus and ordinary differential equations This newly revised second edition features an additional appendix concerning the approximate evaluation of integrals   Qualitative Analysis of Physical Problems M Gitterman,2012-12-02 Qualitative Analysis of Physical Problems reviews the essential features of all the main approaches used for the qualitative analysis of physical problems and demonstrates their application to problems from a wide variety of fields Topics covered include model construction dimensional analysis symmetry and the method of the small parameter This book consists of six chapters and begins by looking at various approaches for the construction of models along with nontrivial applications of dimensional analysis to some typical model systems The following chapters focus on the application of symmetry to the microscopic and macroscopic properties of systems the implications of analyticity and occurrence of singularities and some methods of deriving the magnitude of the solutions that is approximate numerical values for problems that usually cannot be solved exactly in closed form The final chapter demonstrates the use of qualitative analysis to address the problem of second harmonic generation in nonlinear optics This monograph will be a useful resource for graduate students experimental and theoretical physicists chemists engineers college and high school teachers and those who are interested in obtaining a general perspective of modern physics   **Singular-Perturbation Theory** Donald R. Smith,1985-08-30 Introduction to singular perturbation problems Since the nature of the nonuniformity can vary from case to case the author considers and solves a variety of problems mostly for ordinary differential equations   *Introduction to the General Theory of Singular Perturbations* S. A. Lomov, This book is aimed at researchers and students in physics mathematics and engineering It contains the first systematic presentation of a general approach to the integration of singularly perturbed differential equations describing nonuniform transitions such as the occurrence of a boundary layer

discontinuities boundary effects and so on The method of regularization of singular perturbations presented here can be applied to the asymptotic integration of systems of ordinary and partial differential equations   *Problems in perturbation* Ali Hasan Nayfeh,1985   **Problems in Singular Perturbation Theory** James Alan Cochran,1962   **KWIC Index for Numerical Algebra** Alston Scott Householder,1972   **A Generalized Method for Treating Singular Perturbation Problems** Ali Hasan Nayfeh,Stanford University. Department of Aeronautics and Astronautics,1964 Some of the existing methods of treating singular perturbation problems are studied and a generalized method for solving such problems is developed The generalized method was applied to a restricted three body problem and to a general second order linear ordinary differential equation with a turning point of arbitrary order The results of the latter are used in obtaining the asymptotic expansions of the eigenvalues and eigenfunctions of a second order linear equation with two turning points of arbitrary order A special case of the eigenvalue problem is the Graetz problem It arises in finding the temperature distribution of a fluid with constant properties having a parabolic velocity profile which enters suddenly into a round tube whose wall is kept at a different constant temperature Author   **Problems in Perturbation** Ali H. Nayfeh,1985-08-07 This self contained volume explains perturbation techniques by means of solved problems Ideal for self study it provides 360 solved problems and an almost equal number of supplementary problems   *Perturbation Theory in Periodic Problems for Two-Dimensional Integrable Systems* I. M. Krichever,1992   *Perturbation Methods for Differential Equations* Bhimsen Shivamoggi,2002-12-13 Perturbation methods are widely used in the study of physically significant differential equations which arise in Applied Mathematics Physics and Engineering Background material is provided in each chapter along with illustrative examples problems and solutions A comprehensive bibliography and index complete the work Covers an important field of solutions for engineering and the physical sciences To allow an interdisciplinary readership the book focuses almost exclusively on the procedures and the underlying ideas and soft pedal the proofs Dr Bhimsen K Shivamoggi has authored seven successful books for various publishers like John Wiley Sons and Kluwer Academic Publishers

Geometric Singular Perturbation Theory Beyond the Standard Form Martin Wechselberger,2020-02-21 This volume provides a comprehensive review of multiple scale dynamical systems Mathematical models of such multiple scale systems are considered singular perturbation problems and this volume focuses on the geometric approach known as Geometric Singular Perturbation Theory GSPT It is the first of its kind that introduces the GSPT in a coordinate independent manner This is motivated by specific examples of biochemical reaction networks electronic circuit and mechanic oscillator models and advection reaction diffusion models all with an inherent non uniform scale splitting which identifies these examples as singular perturbation problems beyond the standard form The contents cover a general framework for this GSPT beyond the standard form including canard theory concrete applications and instructive qualitative models It contains many illustrations and key pointers to the existing literature The target audience are senior undergraduates graduate students and researchers

interested in using the GSPT toolbox in nonlinear science either from a theoretical or an application point of view Martin Wechselberger is Professor at the School of Mathematics Statistics University of Sydney Australia He received the J D Crawford Prize in 2017 by the Society for Industrial and Applied Mathematics SIAM for achievements in the field of dynamical systems with multiple time scales   <u>The Princeton Companion to Applied Mathematics</u> Nicholas J. Higham,Mark R. Dennis,Paul Glendinning,Paul A. Martin,Fadil Santosa,Jared Tanner,2015-09-15 The must have compendium on applied mathematics This is the most authoritative and accessible single volume reference book on applied mathematics Featuring numerous entries by leading experts and organized thematically it introduces readers to applied mathematics and its uses explains key concepts describes important equations laws and functions looks at exciting areas of research covers modeling and simulation explores areas of application and more Modeled on the popular Princeton Companion to Mathematics this volume is an indispensable resource for undergraduate and graduate students researchers and practitioners in other disciplines seeking a user friendly reference book on applied mathematics Features nearly 200 entries organized thematically and written by an international team of distinguished contributors Presents the major ideas and branches of applied mathematics in a clear and accessible way Explains important mathematical concepts methods equations and applications Introduces the language of applied mathematics and the goals of applied mathematical research Gives a wide range of examples of mathematical modeling Covers continuum mechanics dynamical systems numerical analysis discrete and combinatorial mathematics mathematical physics and much more Explores the connections between applied mathematics and other disciplines Includes suggestions for further reading cross references and a comprehensive index   *Operations Research and Cyber-Infrastructure* John W. Chinneck,Bjarni Kristjansson,Matthew J. Saltzman,2009-01-05 Operations Research and Cyber Infrastructure is the companion volume to the Eleventh INFORMS Computing Society Conference ICS 2009 held in Charleston South Carolina from January 11 to 13 2009 It includes 24 high quality refereed research papers As always the focus of interest for ICS is the interface between Operations Research and Computer Science and the papers in this volume reflect that interest This is naturally an evolving area as computational power increases rapidly while decreasing in cost even more quickly and the papers included here illustrate the wide range of topics at this interface   *Advanced Partial Differential Equations* Sameer Kulkarni,2025-02-28 Embark on an in depth exploration of partial differential equations PDEs with Advanced Partial Differential Equations Our comprehensive guide provides a thorough overview of the theory numerical methods and practical applications of PDEs across various scientific and engineering fields This resource is designed for both graduate level students and professionals seeking to deepen their understanding of PDEs We cover a wide range of topics from classical PDEs and numerical methods to applications in physics engineering biology and finance Additionally we delve into advanced topics such as nonlinear equations and stochastic processes presenting each subject with rigorous mathematical treatment and clear explanations Our guide includes detailed discussions on numerical

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