

## Homework Set #5 – Solutions

1. This problem is essentially Messiah, Chapter 18, Problem 4 (or Sakurai, Chapter 5, Problem 1). Consider a one-dimensional harmonic oscillator perturbed by a constant force

$$H = \frac{p^2}{2m} + \frac{1}{2}m\omega^2 x^2 - Fx$$

- a) Show that the first order perturbation in the energy levels vanishes.

Since we will need to find the second order perturbation in part b), let us consider the general matrix element

$$V_{mn} = -F \langle m^{(0)} | x | n^{(0)} \rangle$$

The operator  $x$  is given in terms of creation and annihilation operators by  $x = \sqrt{\hbar/(2m\omega)}(a^\dagger + a)$ . Thus

$$\begin{aligned} V_{mn} &= -F \sqrt{\frac{\hbar}{2m\omega}} \langle m^{(0)} | (a^\dagger + a) | n^{(0)} \rangle \\ &= -F \sqrt{\frac{\hbar}{2m\omega}} [\sqrt{n+1} \delta_{m,n+1} + \sqrt{n} \delta_{m,n-1}] \end{aligned}$$

This indicates that the  $x$  operator changes the oscillator number by  $\pm 1$ . In particular,  $V_{nn} = 0$ , which demonstrates that the first order energy perturbation vanishes.

- b) Now calculate the eigenenergies  $E_n$  up to second order in the perturbation.

Using the matrix element calculated above, we find

$$\begin{aligned} E_n^{(2)} &= \sum_{k \neq n} \frac{|V_{kn}|^2}{E_n^{(0)} - E_k^{(0)}} = \frac{|V_{n+1,n}|^2}{E_n^{(0)} - E_{n+1}^{(0)}} + \frac{|V_{n-1,n}|^2}{E_n^{(0)} - E_{n-1}^{(0)}} \\ &= F^2 \frac{\hbar}{2m\omega} \left[ \frac{n+1}{-\hbar\omega} + \frac{n}{\hbar\omega} \right] = -\frac{F^2}{2m\omega^2} \end{aligned}$$

Combined with the zeroth order energy, this gives

$$E_n = (n + \frac{1}{2})\hbar\omega - \frac{F^2}{2m\omega^2}$$

- c) Show that the second-order perturbation result gives the exact eigenenergies (which may be obtained by completing the square in  $H$ ). Explain why this happens.

# Sakurai Solutions Chapter 4

**Yoshiyuki Kikuchi**



## Sakurai Solutions Chapter 4:

*Princeton Problems in Physics with Solutions* Nathan Newbury, Mark Newman, 2015-03-25 Aimed at helping the physics student to develop a solid grasp of basic graduate level material this book presents worked solutions to a wide range of informative problems These problems have been culled from the preliminary and general examinations created by the physics department at Princeton University for its graduate program The authors all students who have successfully completed the examinations selected these problems on the basis of usefulness interest and originality and have provided highly detailed solutions to each one Their book will be a valuable resource not only to other students but to college physics teachers as well The first four chapters pose problems in the areas of mechanics electricity and magnetism quantum mechanics and thermodynamics and statistical mechanics thereby serving as a review of material typically covered in undergraduate courses Later chapters deal with material new to most first year graduate students challenging them on such topics as condensed matter relativity and astrophysics nuclear physics elementary particles and atomic and general physics

Problems in the Theory of Point Explosion in Gases Viktor Pavlovich Korobeinikov, 1976      **Solutions Manual,**

**Perspectives on Structure and Mechanism in Organic Chemistry** Felix A. Carroll, 1997 Includes solutions to all problems      **High-Velocity Impact Phenomena** Ray Kinslow, 2012-12-02 High Velocity Impact Phenomena covers a wide

range of pertinent topics dealing with impact phenomena The book discusses hypervelocity accelerators stress wave propagation in solids and the theory of impact The text also describes the application of the theory of impact on thin targets and shields and correlation with experiment the numerical evaluation of hypervelocity impact phenomena and analytical studies of impact generated shock propagation The equation of state of solids from shock wave studies metallurgical observations and energy partitioning and engineering considerations in hypervelocity impact are also encompassed Design engineers will find the book invaluable      **Linear and Nonlinear Waves** G. B. Whitham, 2011-10-18 Now in an accessible

paperback edition this classic work is just as relevant as when it first appeared in 1974 due to the increased use of nonlinear waves It covers the behavior of waves in two parts with the first part addressing hyperbolic waves and the second addressing dispersive waves The mathematical principles are presented along with examples of specific cases in communications and specific physical fields including flood waves in rivers waves in glaciers traffic flow sonic booms blast waves and ocean waves from storms      The Physics of Alfvén Waves Neil F. Cramer, 2011-02-10 Low frequency wave modes of magnetized

inhomogeneous plasmas have been subject to intense study in the last decade because they play important roles in the transport of energy in the plasmas The Alfvén wave heating scheme has been investigated as a supplementary heating scheme for fusion plasma devices and it has been invoked as a model of the heating of the solar and stellar coronae This book covers the latest research into the properties and applications of low frequency wave modes in magnetized plasmas the Alfvén waves and magneto acoustic waves in the context of laboratory space and astrophysical plasmas In particular non ideal

effects on the dispersion relation and absorption properties of linear and non linear waves are included such as ion cyclotron effects friction between the ionized plasma and a background gas of neutral atoms and the interaction of the plasma with dust particles The book also surveys the theory of Alfvén and magnetoacoustic waves in inhomogeneous plasmas as occur in realistic laboratory space and astrophysical plasmas with resulting localized wave modes such as surface waves Waves are considered under a variety of plasma conditions ranging from cold cosmic plasmas to hot laboratory and solar plasmas to the relativistic plasmas around pulsars

**Water and Biomolecules** Kunihiro Kuwajima, Yuji Goto, Fumio Hirata, Masahide Terazima, Mikio Kataoka, 2009-03-18 Life is produced by the interplay of water and biomolecules This book deals with the physicochemical aspects of such life phenomena produced by water and biomolecules and addresses topics including Protein Dynamics and Functions Protein and DNA Folding and Protein Amyloidosis All sections have been written by internationally recognized front line researchers The idea for this book was born at the 5th International Symposium Water and

**Biomolecules** held in Nara city Japan in 2008 **The Great Gap** Merike Blofield, 2015-08-21 The relationship between socioeconomic inequality and democratic politics has been one of the central questions in the social sciences from Aristotle on Recent waves of democratization combined with deepened global inequalities have made understanding this relationship ever more crucial In The Great Gap Merike Blofield seeks to contribute to this understanding by analyzing inequality and politics in the region with the highest socioeconomic inequalities in the world Latin America The chapters written by prominent scholars in their fields address the socioeconomic context and inequality of opportunities elite culture public opinion and media framing capital mobility campaign financing representation and gender equality policies and taxation and social policies Aside from the editor the contributors are Pablo Alegre Mauricio Bugarin Daniela Campello Anna Crespo Francisco H G Ferreira Fernando Filgueira Liesl Haas Sallie Hughes Juan Pablo Luna James E Mahon Jr Juliana Martinez Franzoni Adriana Cuoco Portugal Paola Prado Elisa P Reis Luis Reygadas Sergio Naruhiko Sakurai and Koen Voorend

**Anglo-American Connections in Japanese Chemistry** Yoshiyuki Kikuchi, 2013-12-18 Anglo Japanese and American Japanese connections in chemistry had a major impact on the institutionalization of scientific and technological higher education in Japan from the late nineteenth century and onwards They helped define the structure of Japanese scientific pedagogical and research system that lasted well into the post World War II period of massive technological development when it became one of the biggest providers of chemists and chemical engineers in the world next to Europe and the United States In telling this story Anglo American Connections in Japanese Chemistry explores various sites of science education such as teaching laboratories and classrooms where British and American teachers mingled with Japanese students to shed new light on the lab as a site of global human encounter and intricate social relations that shaped scientific practice An Interpretive Introduction to Quantum Field Theory Paul Teller, 2020-07-21 Quantum mechanics is a subject that has captured the imagination of a surprisingly broad range of thinkers including many philosophers of science Quantum field theory

however is a subject that has been discussed mostly by physicists This is the first book to present quantum field theory in a manner that makes it accessible to philosophers Because it presents a lucid view of the theory and debates that surround the theory An Interpretive Introduction to Quantum Field Theory will interest students of physics as well as students of philosophy Paul Teller presents the basic ideas of quantum field theory in a way that is understandable to readers who are familiar with non relativistic quantum mechanics He provides information about the physics of the theory without calculational detail and he enlightens readers on how to think about the theory physically Along the way he dismantles some popular myths and clarifies the novel ways in which quantum field theory is both a theory about fields and about particles His goal is to raise questions about the philosophical implications of the theory and to offer some tentative interpretive views of his own This provocative and thoughtful book challenges philosophers to extend their thinking beyond the realm of quantum mechanics and it challenges physicists to consider the philosophical issues that their explorations have encouraged

**Modern Gas-Based Temperature and Pressure Measurements** Franco Pavese, Gianfranco Molinar Min Beciet, 2013-06-29 Since the beginning of the preparation of this volume we have been convinced that temperature and pressure measurements should not be separated particularly in different applications at low temperatures This belief has made us deeply conscious of the fact that the advanced applications and modern experimental methods of investigation in science and technology need the combination of various professional experiences and approaches Although the book is divided into two parts Part I by F Pavese and Part II by G F Molinar we have tried to correlate low temperature and low pressure measurements as much as possible We hope that our readers will find this book which contains a large number of experimental and reference data useful in their effort to solve measurement problems We are pleased to acknowledge our debt to several persons and wish to express our gratitude to them for their valuable cooperation and help to our research group colleagues at the Istituto di Metrologia G Colonnetti IMGC CNR without whom the knowledge and the experience we built up during many years could not have been acquired to G T McConville M Durieux and K Grohmann for revisions of and various suggestions for Part I to V E Bean and C R Tilford of NIST and G T McConville for revisions of and various suggestions for Part II and to I Prinetti of IMGC for many valuable suggestions and careful textual revisions

**The Finite Element Method for Solid and Structural Mechanics** O. C. Zienkiewicz, R. L. Taylor, 2013-11-08 The Finite Element Method for Solid and Structural Mechanics is the key text and reference for engineers researchers and senior students dealing with the analysis and modeling of structures from large civil engineering projects such as dams to aircraft structures and small engineered components This edition brings a thorough update and rearrangement of the book's content including new chapters on Material constitution using representative volume elements Differential geometry and calculus on manifolds Background mathematics and linear shell theory Focusing on the core knowledge mathematical and analytical tools needed for successful structural analysis and modeling The Finite Element Method for Solid and Structural Mechanics is the

authoritative resource of choice for graduate level students researchers and professional engineers A proven keystone reference in the library of any engineer needing to apply the finite element method to solid mechanics and structural design Founded by an influential pioneer in the field and updated in this seventh edition by an author team incorporating academic authority and industrial simulation experience Features new chapters on topics including material constitution using representative volume elements as well as consolidated and expanded sections on rod and shell models      *Modeling of Thermo-Electro-Mechanical Manufacturing Processes* C. V. Nielsen, W. Zhang, L. M. Alves, N. Bay, Niels Bay, 2012-10-08

Modeling of Thermo Electro Mechanical Manufacturing Processes with Applications in Metal Forming and Resistance Welding provides readers with a basic understanding of the fundamental ingredients in plasticity heat transfer and electricity that are necessary to develop and properly utilize computer programs based on the finite element flow formulation Computer implementation of a wide range of theoretical and numerical subjects related to mesh generation contact algorithms elasticity anisotropic constitutive equations solution procedures and parallelization of equation solvers is comprehensively described Illustrated and enriched with selected examples obtained from industrial applications Modeling of Thermo Electro Mechanical Manufacturing Processes with Applications in Metal Forming and Resistance Welding works to diminish the gap between the developers of finite element computer programs and the professional engineers with expertise in industrial joining technologies by metal forming and resistance welding      *Cadmium in Soils and Plants* M.J. McLaughlin, B.R. Singh, 2012-12-06

Over forty years ago concern was first focussed on cadmium contamination of soils fertilisers and the food chain Adverse effects on human health were first highlighted nearly 30 years ago in Japan with the outbreak of Itai itai disease Since then substantial research data have accumulated for cadmium on chemistry in soils additions to soils uptake by plants adverse effects on the soil biota and transfer through the food chain However this information has never been compiled into a single volume This was the stimulus for the Kevin G Tiller Memorial Symposium Cadmium in Soils Plants and the Food Chain held at the University of California Berkeley in June 1997 as part of the Fourth International Conference on the Biogeochemistry of Trace Elements This symposium brought together leading scientists in the field of cadmium behaviour in soils and plants to review the scientific data in the literature and highlight gaps in our current knowledge of the subject This series of review papers are presented here and deal with the chemistry of cadmium in soils the potential for transfer through the food chain and management to minimise this problem We hope this information provides a sound scientific basis to assist development of policies and regulations for controlling cadmium in the soil environment      **VLSI** Tomasz Wojcicki, 2017-12-19

Recently the world celebrated the 60th anniversary of the invention of the first transistor The first integrated circuit IC was built a decade later with the first microprocessor designed in the early 1970s Today ICs are a part of nearly every aspect of our daily lives They help us live longer and more comfortably and do more faster All this is possible because of the relentless search for new materials circuit designs and ideas happening on a daily basis at industrial

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*Novel Synthesis and Characterization of Nanostructured Materials* Annelise Kopp Alves, Carlos P. Bergmann, Felipe Amorim Berutti, 2013-10-18 Nanostructured materials have been largely studied in the last few years They have great potential of applications in different fields such as materials science physics chemistry biology mechanic and medicine Synthesis and characterization of nanostructured materials is a subject of great interest involving science market politicians government and society Based on results obtained by the authors research group during the past decade this book comes to present novel techniques to synthesize nanostructured materials and characterize their properties such as crystallinity and crystallite size specific surface area particle size morphology and catalytic activity This book is aimed for students researchers and engineers searching for methodologies to obtain and characterize nanostructures in details

Networks on Chips Giovanni De Micheli, Luca Benini, 2006-08-30 The design of today s semiconductor chips for various applications such as telecommunications poses various challenges due to the complexity of these systems These highly complex systems on chips demand new approaches to connect and manage the communication between on chip processing and storage components and networks on chips NoCs provide a powerful solution This book is the first to provide a unified overview of NoC technology It includes in depth analysis of all the on chip communication challenges from physical wiring implementation up to software architecture and a complete classification of their various Network on Chip approaches and solutions Leading edge research from world renowned experts in academia and industry with state of the art technology implementations trends An integrated presentation not currently available in any other book A thorough introduction to current design methodologies and chips designed with NoCs

**Radiation Dosimetry Phosphors** Sanjay J. Dhoble, Vibha Chopra, Vinit Nayar, George Kitis, Dirk Poelman, Hendrik C. Swart, 2022-05-26 Radiation Dosimetry Phosphors provides an overview of the synthesis properties and applications of materials used for radiation dosimetry and reviews the most appropriate phosphor materials for each radiation dosimetry

technique The book describes the available phosphors used commercially for their applications in the medical field for dose measurements Although radiation dosimetry phosphors are commercially available continuous efforts have been made by the worldwide research community to develop new materials or improve already existing materials used in different areas with low or high levels of radiation Moreover researchers are still working on developing dosimetric phosphors for OSL ML LL and RPL dosimetry This book provides an overall view of the phosphors available low cost synthesis methods mechanisms involved emerging trends and new challenges for the development of emerging materials for radiation dosimetry It is suitable for those working in academia and R D laboratories in the discipline of materials science and engineering along with practitioners working in radiation and dosimetry Provides the fundamental concepts historical context and review of current phosphors available for radiation dosimetry Reviews low cost material methods to synthesize and characterize rare earth doped inorganic phosphors for different kinds of radiation dosimetry techniques Discusses key barriers and potential solutions for enabling commercial realization phosphors for radiation dosimetry applications

**Network and Traffic Engineering in Emerging Distributed Computing Applications** Abawajy, Jemal H., Pathan, Mukaddim, Rahman, Mustafizur, Pathan, Al-Sakib Khan, Deris, Mustafa Mat, 2012-07-31 This book focuses on network management and traffic engineering for Internet and distributed computing technologies as well as present emerging technology trends and advanced platforms Provided by publisher

**Controlling the Morphology of Polymers** Geoffrey R. Mitchell, Ana Tojeira, 2016-09-06 This book focuses on controlling morphology of different scales for polymers The authors explain the need for successful control of morphology to yield target macroscopic physical properties in the application of polymers to diverse areas such as engineering materials nanodielectrics and photonic crystals The book combines specialized chapters with an introduction to the morphology of polymers and the range of experimental techniques available to evaluate it

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