GENERAL

modern quantum mechanics sakurai solutions

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Modern Quantum Mechanics Sakurai Solutions: A Comprehensive Guide

Quantum mechanics is the cornerstone of modern physics, offering a framework that explains phenomena ranging from atomic spectra to the behavior of subatomic particles. Among the many texts that have shaped the way students and researchers approach the subject, *Modern Quantum Mechanics* by J. J. Sakurai stands out for its clarity, depth, and elegant problem solving techniques. This article dives deep into the solutions of Sakurai's textbook, exploring the methods that make the book a staple in graduate courses worldwide. Whether you're a first year physics student, an advanced undergraduate, or a researcher looking to refresh your toolbox, you'll find valuable insights and practical examples that illuminate the art of solving quantum problems.

Why Sakurai Is a Benchmark for Modern Quantum Mechanics

J. J. Sakurai's *Modern Quantum Mechanics* has earned its reputation for several reasons:

- Conceptual Focus: The book emphasizes the underlying principles—Hilbert spaces, operators, and symmetry —before diving into calculations.
- Operator Methodology: Sakurai's reliance on operator algebra offers a powerful, general approach that transcends specific coordinate systems.
- Problem Solving Emphasis: Each chapter concludes with a series of problems that encourage active learning; many of these problems have become iconic in the quantum mechanics community.
- Historical Context: The author weaves the evolution of quantum theory into the narrative, helping readers appreciate the conceptual leaps that led to the modern formulation.

Because of these strengths, the solutions to Sakurai's problems are highly sought after. They not only provide step by step guidance but also reveal the underlying intuition that the textbook often hints at. In the following sections, we'll walk through the key problem solving strategies, illustrate them with concrete examples, and discuss how to apply them to new, uncharted problems.

Core Concepts Revisited: The Building Blocks of Sakurai Solutions

Before tackling the solutions themselves, it's essential to revisit the foundational concepts that Sakurai uses throughout his text. Mastery of these ideas will make the solutions more transparent and empower you to adapt them to new contexts.

1. Hilbert Space and State Vectors

In Sakurai, the state of a quantum system is represented by a vector in a complex Hilbert space. The inner product 'è<‡À <b~• defines the probability amplitude between two states, while the norm ||<‡ÇÀ must be one for a normalized state. Many problems revolve around manipulating these vectors, projecting onto bases, and calculating expectation values.

2. Operators and Observables

Observables are represented by Hermitian operators. Sakurai's solutions frequently involve commutation relations, spectral decomposition, and the use of ladder operators to find eigenvalues and eigenvectors. Understanding how operators act on state vectors is crucial for navigating the solution steps.

3. Commutation Relations and Uncertainty

The canonical commutation relation [x, p] = i p underpins the uncertainty principle and many derivations. Sakurai's problems often ask you to compute commutators or to use them to derive operator identities, so a solid grasp of these relations is indispensable.

4. Symmetry and Conservation Laws

Symmetry operations—rotations, translations, and reflections—are represented by unitary operators. Sakurai's solutions exploit these symmetries to simplify problems, especially those involving angular momentum and spin.

5. Time Evolution and the Schrödinger Equation

Time dependence is introduced via the time dependent Schrödinger equation (TDSE) or the Heisenberg picture. Sakurai's solutions frequently involve solving the TDSE for specific potentials or applying time evolution operators to stationary states.

Approach to Solving Sakurai Problems: A Step by Step Framework

While each problem in Sakurai is unique, most solutions share a common structure. Below is a generalized framework that you can adapt to almost any exercise in the textbook.

1. Understand the Problem Statement: Identify the given information, what is being asked, and any constraints (e.g., boundary conditions).
2. Choose an Appropriate Basis: Decide whether the position, momentum, or energy basis simplifies the calculations.
3. Write Down Relevant Operators: Express the operators involved (Hamiltonian, angular momentum, etc.) in the chosen basis.
4. Apply Commutation Relations: Use known commutators to simplify expressions or to derive new operator identities.
5. Solve Eigenvalue Equations: Find the eigenstates and eigenvalues of the operator(s) in question.
6. Compute Probabilities or Expectation Values: Use the inner product and normalization conditions to evaluate the desired quantities.
7. Interpret the Result Physically: Relate the mathematical outcome to physical intuition, ensuring consistency with known principles.

Below we illustrate this framework with detailed solutions to several representative Sakurai exercises.

Example 1: Commutation of Angular Momentum Operators

Problem: Show that the components of the angular momentum operator satisfy the commutation relation [L_x, /L_y] /= /i r ôÅ÷¢à

Solution:

1. Recall that L = r /× /p and its components are L_x /= /y /p_z /- /z /p_y, L_y /= /z /p_x /- /x /p_z, and L_z /= /x /p_y /- /y /p_x
2. Compute [L_x, /L_y] by expanding the commutator:

[L_x, /L_y] = (y /p_z /- /z /p_y)(z /p_x /- /x /p_z) - (z /p_x /- /x /p_z)(y /p_z /- /z /p_y)

3. Use the canonical commutation relations [x_i, /p_j] /= /i r ó´_{ij} and the fact that position and momentum operators along different axes commute.
4. After careful algebra, all terms cancel except those proportional to i r ôÅ÷¢Â —VÆF–æs

[L_x, /L_y] = i r ôÅ÷

5. Interpretation: The non commutativity of angular momentum components reflects the intrinsic rotational symmetry of quantum systems.

This straightforward example demonstrates how the operator approach can yield elegant results with minimal calculation.

Example 2: Solving the One Dimensional Infinite Square Well

Problem: Find the energy eigenvalues and eigenfunctions for a particle in a one dimensional infinite potential well of width L.

Solution:

1. Set up the Hamiltonian:

H = p²/(2m) + V(x), where V(x) = 0 for 0

2. Inside the well, the TDSE reduces to:

- ({"ó&Ò' öK#È/dx² = E /<€

3. The general solution is a linear combination of sines and cosines:

<,‡,' Ò ÷6–â†·,' ² " ö6÷2†·,'Â 6² Ò !¢ƒ&ÔR'ñ'

4. Apply boundary conditions <,ƒ ' Ò æB È(L) = 0. The first condition forces B = 0; the second yields sin(kL) = 0, so kL = n< †â Ò Â "Â 2Â R'à

5. Thus,

k = n< ôÂ 2 " 4Uöâ Ò •'²< &ë"'òƒ&ÔË"•

6. Normalize <…öâ‡,“

<…öâ‡,' Ò !¢ƒ"ôÂ' ÷6–â†ãÀx/L)

7. Interpretation: The quantization of energy levels arises from the boundary conditions imposed by the infinite potential walls.

In this example, the key steps are setting up the differential equation, applying boundary conditions, and normalizing the wavefunction—steps that recur in many Sakurai exercises.

Example 3: Ladder Operators for the Quantum Harmonic Oscillator

Problem: Derive the action of the raising and lowering operators on the harmonic oscillator eigenstates.

Solution:

1. Define the ladder operators:

a = (1/" (2 vÓÉ)) /(m<—, ² — 'Â 6 b Ò ƒ ò!¢ƒ!'m<'' ò†ÓÉx - ip)

2. Show that [a, /a†] = 1 using the canonical commutation relation.
3. Express the Hamiltonian in terms of a and a†:

H = sÉ (a†a + 1/2)

4. Assume |n'é is an eigenstate of H with eigenvalue E_n = sÉ(n + 1/2). Apply a and a†:

a|n'é = " n /|n-1'é, a†|n'é = " (n+1) /|n+1'é

5. Derive these relations by acting with a on |n'é and using the commutation relations to shift the energy eigenvalue.

6. Interpretation: Ladder operators provide a systematic way to generate the entire spectrum from the ground state, illustrating the algebraic structure underlying the oscillator.

These solutions exemplify how operator algebra can simplify seemingly complex differential equations.

Advanced Topics Covered in Sakurai Solutions

Beyond the classic textbook problems, Sakurai delves into topics that challenge even seasoned physicists. The solutions to these problems often require a blend of mathematical sophistication and physical insight.

1. Spin Systems and the Pauli Matrices

Problems involving spin-½ particles demand proficiency with the Pauli matrices <5÷,À <5÷•, <5÷ and their algebra. Solutions typically involve constructing spinors, calculating expectation values, and exploring the implications of spin precession.

2. Time Dependent Perturbation Theory

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