

2016 Fall Semester

2016



424 Physics “Quantum Mechanics II”

Instructor: Prof. Slava V. Rotkin
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610-758-3904; Office: Lewis 414
Class: 9:20 am - 10:35 am TR Lewis 511

Prerequisites: PHY 369 (or equivalent course in quantum physics) and its prerequisites.

Credits: 3

Grades will be based on

- midterm exam (25%),
- homework and quiz (20%)
- textbook reading assignments and class/discussion activity (15%)
- final exam (40%)

Expectations:

You should expect to spend at least an hour of outside class study for every hour in class in addition to approximately an hour doing a homework assignment. Many students find it helpful to form study groups to work and discuss homework assignments with other students which is encouraged. It is an excellent way to learn physics. However, it is expected that finally each student will know how to work his problem for quiz, midterm or final without help. If you get stuck on a homework problem, see your instructor for help.

Office hours: TR 1:15 - 2:30 (schedule the meeting)

Textbook: "Quantum Mechanics with Basic Field Theory" by Bipin R. Desai, Cambridge University Press; (2009) # ISBN-10: 0521877601 # ISBN-13: 978-0521877602

Recommended reading:

- **L. D. Landau and E. M. Lifshitz, *Quantum Mechanics (Non-Relativistic Theory)***
- J.J. Sakurai: Modern Quantum Mechanics, Addison-Wesley (1994)
- A. Messiah, Quantum Mechanics
- L. I. Schiff, Quantum Mechanics
- Eugen Merzbacher: Quantum Mechanics, (3rd edition), Wiley, 1998.
- W. Thirring: Course in Theoretical Physics 3: Quantum Mechanics of Atoms and Molecules, Springer-Verlag (1990)
- D. Bohm: Quantum Mechanics; Foundations and Applications, 3rd edition, Springer-Verlag (1994)

Accommodations for Students with Disabilities: If you have a disability for which you are or may be requesting accommodations, please contact both your instructor and the Office of Academic Support Services, Williams Hall, Suite 301 (610-758-4152) as early as possible in the semester. You must have documentation from the Academic Support Services office before accommodations can be granted.

The Principles of Our Equitable Community: Lehigh University endorses The Principles of Our Equitable Community [http://www.lehigh.edu/~inprv/initiatives/PrinciplesEquity_Sheet_v2_032212.pdf]. We expect each member of this class to acknowledge and practice these Principles. Respect for each other and for differing viewpoints is a vital component of the learning environment inside and outside the classroom.

Course Syllabus

0. Basics of Quantum Mechanics. Dynamical equations. Perturbation theory

Preliminary reading assignment: Refresh your memories on fundamentals of matrix QM (Ch. 1-13).

(Time evolution operator, Schrödinger, Heisenberg and interaction picture. Two-level system: time-independent and time-dependent problems. Perturbation theory: time-independent perturbation.)

Part I. Solving time-dependent problems of quantum mechanics

17. Time-dependent perturbation /we follow textbook Chapter and page numbering/

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| 17.1 Basic formalism | 293 |
| 17.2 Harmonic perturbation and Fermi's golden rule | 296 |
| 17.3 Transitions into a group of states and scattering cross-section | 299 |
| 17.4 Resonance and decay | 303 |

18. Interaction of charged particles and radiation in perturbation theory.

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| 18.1 Electron in an electromagnetic field: the absorption cross-section | 318 |
| 18.2 Photoelectric effect | 323 |
| 18.3 Coulomb excitations of an atom | 325 |
| 18.4 Ionization | 328 |
| 18.5 Thomson, Rayleigh, and Raman scattering in second-order perturbation | 331 |

Part II. Scattering in quantum mechanics

19. Scattering in one dimension. (independent study)

(Reading assignment)

| | |
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| 19.1 Reflection and transmission coefficients | 342 |
| 19.2 Infinite barrier | 344 |
| 19.3 Finite barrier with infinite range | 345 |
| 19.4 Rigid wall preceded by a potential well | 348 |
| 19.5 Square-well potential and resonances | 351 |
| 19.6 Tunneling | 354 |

QUIZ on 1D scattering

20. Scattering in three dimensions – a formal theory.

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| 20.1 Formal solutions in terms of Green's function | 358 |
| 20.2 Lippmann–Schwinger equation | 360 |
| 20.3 Born approximation | 363 |
| 20.4 Scattering from a Yukawa potential | 364 |
| 20.5 Rutherford scattering | 365 |
| 20.6 Charge distribution | 366 |
| 20.7 Probability conservation and the optical theorem | 367 |
| 20.8 Absorption | 370 |
| 20.9 Relation between the T-matrix and the scattering amplitude | 372 |
| 20.10 The S-matrix | 374 |
| 20.11 Unitarity of the S-matrix and the relation between S and T | 378 |
| 20.12 Properties of the T-matrix and the optical theorem (again) | 382 |

21. Partial wave amplitudes and phase shifts.

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| 21.1 Scattering amplitude in terms of phase shifts | 386 |
| 21.2 χ_l , K_l , and T_l | 392 |
| 21.3 Integral relations for χ_l , K_l , and T_l | 393 |
| 21.4 Wronskian | 395 |

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| 21.5 Calculation of phase shifts: some examples | 400 |
| *22. Analytic structure of the S-matrix. | |
| *22.1 S-matrix poles | 407 |
| *22.2 Jost function formalism | 413 |
| *22.3 Levinson's theorem | 420 |
| *22.4 Explicit calculation of the Jost function for $l = 0$ | 421 |
| *22.5 Integral representation of $F_0(k)$ | 424 |
| <u>Part III. Advanced theory of angular momentum</u> | |
| 26. Rotations and angular momentum. | |
| 26.1 Rotation of coordinate axes | 479 |
| 26.2 Scalar functions and orbital angular momentum | 483 |
| 26.3 State vectors | 485 |
| 26.4 Transformation of matrix elements and representations of the rotation operator | 487 |
| 26.5 Generators of infinitesimal rotations: their eigenstates and eigenvalues | 489 |
| 26.6 Representations of J^2 and J_i for $j = 1/2$ and $j = 1$ | 494 |
| 26.7 Spherical harmonics | 495 |
| 28. Addition of angular momenta. | |
| 28.1 Combining eigenstates: simple examples | 518 |
| 28.2 Clebsch–Gordan coefficients and their recursion relations | 522 |
| 28.3 Combining spin $1/2$ and orbital angular momentum l | 524 |
| 29. Irreducible tensors and Wigner–Eckart theorem. | |
| 29.1 Irreducible spherical tensors and their properties | 529 |
| 29.2 The irreducible tensors: $Y_{lm}(\theta, \varphi)$ and $D_j(\chi)$ | 533 |
| 29.3 Wigner–Eckart theorem | 536 |
| 29.4 Applications of the Wigner–Eckart theorem | 538 |
| *29.5 $SO(3)$, $SU(2)$ groups and Young's tableau | 541 |
| <u>*Part IV. Additional topics (*if time allows)</u> | |
| *24. Approximation methods for bound states and scattering. | |
| *24.1 WKB approximation | 450 |
| *24.2 Variational method | 458 |
| *24.3 Eikonal approximation | 461 |
| *25. Lagrangian method and Feynman path integrals. | |
| *25. Lagrangian method and Feynman path integrals | 469 |
| *25.1 Euler–Lagrange equations | 469 |
| *25.2 N oscillators and the continuum limit | 471 |
| *25.3 Feynman path integrals | 473 |
| *27. Symmetry in quantum mechanics and symmetry groups. | |
| *27.1 Rotational symmetry | 502 |
| *27.2 Parity transformation | 505 |
| *27.3 Time reversal | 507 |
| *27.4 Symmetry groups | 511 |
| *27.5 $D_j(R)$ for $j = 1/2$ and $j = 1$: examples of $SO(3)$ and $SU(2)$ groups | 514 |
| *30. Entangled states. | |
| *30.1 Definition of an entangled state | 549 |
| *30.2 The singlet state | 551 |
| *30.3 Differentiating the two approaches | 552 |
| *30.4 Bell's inequality | 553 |