科目名　Course Title	
量子力学2(Quantum Mechanics II)	
学科・専攻　Department/Program	**受講年次　Grade**
G30 Physics	3rd
授業形態　Class style	**必修・選択の別　Compulsory or Elective**
講義	* See "Remarks"
時間割コード　Registration code	**開講期・曜日・時限　Semester,Day & Period**
0680430	Fall semester Mon：3
単位数　Credit	**科目区分　Course type**
2	Specialized Courses

担当教員　Instructor	WOJDYLO John Andrew(WOJDYLO John Andrew)
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居室　Room	ES035

講義の目的とねらい　Course purpose

This 2nd course in quantum mechanics is the first half of a full-year course. The goal is to enable students to attain a solid grasp of basic concepts. Underlying the teaching approach is the philosophy that in order to learn well, learners must make it a habit to produce many simple calculations: in this way the mathematical language becomes second nature and students learn not to be overwhelmed by mathematical symbols, and to discern the simple physical principles expressed by them: students learn to express with ease their physical intuition using mathematical language. This approach also instills critical thinking, as students make it a habit to verify statements for themselves and not just believe everything they are told.

The course consists of the equivalent of 15 lectures of examinable material, based on Shankar Chapters 1-10, which constitutes a standard one semester Year 3 topic coverage. In addition, a number of additional sessions will be offered to explain new concepts step by step or to explore quantum phenomena that are easily within reach of the core material -- somewhat like seminars for interest. The intention is to help students grasp the abstract content in the textbook, much of which strikingly contradicts classical intuition; and to see the amazing quantum reality.

Alternatively, students who wish to just pass the unit may choose to work through the two books by Susskind, which cover the same topics (except for identical particles) in a far more elementary way, and submit a reasonable number of solved problems. The books by Susskind are written for people who have not previously learned physics. In this way, non-physics majors such as Biology students can learn concepts at the forefront of physics, such as the path integral, which is useful for computational treatments of the protein-folding problem, opening the possibility of their entry into physics labs such as the computational biology lab in the Department of Physics.

Lectures are usually recorded and most of them are available on Youtube (private channel).

The first three lectures (Susskind1) are an overview of classical mechanics, focusing, via Poisson brackets and Lagrangian and Hamiltonian mechanics, on the connection between symmetry and conservation laws. Thus students are introduced to the viewpoint at the heart of present-day physics, one that is essential next semester in Quantum Mechanics III. An extra optional lecture (Goldstein) describes in more depth the structure of classical phase space and generators of infinitesimal canonical transformations. Lecture 4 (Susskind2) is an intuitive justification for the mathematical objects required to describe nature at the atomic scale. Next, in order to make inroads into Shankar, we choose to consider carefully the Mathematical Tools of QM (Cohen-Tannoudji, Chapter 2), such as Dirac notation and its usage, then the Postulates of Quantum Mechanics (Cohen-Tannoudji, Chapter 3), which is really just a more in-depth treatment of Lecture 4. After a lecture covering the rest of Shankar Chapter 1 – normal coordinates; Hermitian operators in infinite dimensions; the basics of Hilbert ' s 1910 abstract formulation of PDE boundary value problems – we find ourselves already in Shankar Chapter 5, with the advantage, compared to standard treatments, of a strong grasp of the machinery of quantum mechanics. The rest of the course follows Shankar closely, apart from Lectures 14 and 15, which, based on Susskind2, expand on ideas encountered in Chapter 10 by considering qubits, tensor product spaces and operators, the density operator, the reduced density operator, pure states and mixed states, the meaning of measurement, and so on, in an exciting setting at the forefront of current research.

Overall, this semester students will gain a solid grounding in basic quantum mechanics. Problem-solving is an integral part of the course: students should attend fortnightly tutorials (Physics Tutorial III) where they will discuss many of the assignment questions and receive hints for solutions. Weaker students are particularly encouraged to attend tutorials and submit assignments. It is recommended that students also enroll in Statistical Physics II concurrently, where they will complement their knowledge with theory of many-particle systems, both classical and quantum.

At the end of Quantum Mechanics III next semester students will be adequately prepared with regards to their knowledge of quantum mechanics to undertake further studies in St-lab, Sp-lab, J-lab, R-lab, TB-lab, E-lab, H-lab, QG-lab and other, including experimental, labs in both the Department of Physics and Department of Applied Physics (e.g. Tanaka Lab), as well as chemistry and computational biology labs at Nagoya University. For chemistry majors, Quantum Mechanics II and III provide a powerful boost to their skills-set which can open many doors.

履修要件　　Prerequisite

Quantum Mechanics 1 or Consent of Instructor.

• Students must have passed Quantum Mechanics 1 to take Quantum Mechanics 2.

履修取り下げの方法について　　How to Apply for Course Withdrawal

<「履修取り下げ届」提出の要・不要 Necessity/Unnecessity to submit "Course Withdrawal Request Form">
Necessary
<条件等 Conditions>
Withdraw by the official deadline in November.

成績評価　Grading

Attendance: 5%; Weekly quizzes or other written assessment: 30%; Mid-semester exam: 32.5%; Final Exam: 32.5%

不可（F）と欠席の基準　Criteria for "Absent" &"Fail" grades

The “ Absent ” grade is reserved for students who withdraw by the official deadline in November. After that day, a letter grade will be awarded based on marks earned from all assessment during the semester.

関連する科目　Related courses

Physics Tutorial III.

It is strongly advised that students concurrently enrol in this tutorial class.

教室　Class room

Check the Course Timetable.
ES035

授業内容　Content

Shankar Chapters 1-10; or Susskind1 and Susskind2. Some topics are more fully explored in tutorials.

Lecture 1. [1] Symmetries and Conservation Laws. What is a state in classical mechanics? How do states evolve? State space, phase space. Why do trajectories never intersect? Newtonian mechanics. Formulation in terms of energy. The Lagrangian. Principle of Least Action. Euler-Lagrange equations. Cyclic coordinates and conserved quantities. (Susskind1)

Lecture 2. [1] Symmetries and Conservation Laws cont ' d. We seek a better way to characterize the connection between symmetries and conservation laws. Poisson brackets. Continuous symmetries. Generators of infinitesimal transformations. Angular momentum is the generator of infinitesimal rotations. Linear momentum is the generator of infinitesimal translations. The Hamiltonian is the generator of infinitesimal time translations. The PB of the Hamiltonian with the generator determines a conservation law if G generates a transformation that leaves the total energy invariant. (Susskind1)

Lecture 3. [0.75] Canonical Transformations: transformations of phase space coordinates (not necessarily infinitesimal) that leave "the physics" unchanged. They map trajectories (i.e. a solution of the equations of motion) into physically equivalent (e.g. rotated) trajectories. (Shankar, Goldstein) NONEXAMINABLE: passive and active transformations. (Shankar, Goldstein)

Optional Lecture 3B. A closer look at: canonical transformations; generators of infinitesimal canonical transformations; symmetry and conservation laws; classical Liouville's Theorem. Phase space is like a flowing incompressible fluid. The flow is a symmetry transformation generated by the Hamiltonian. (Goldstein Ch 8 and 9.)

Lecture 4. [1] Mathematical Tools of QM: A First Look. What kind of mathematics do we need to describe QM experiments? (Based on Susskind2.)

Optional Lecture 4B Mathematical Tools of QM. Introduction. Discrete basis, continuous basis. Orthonormality relations, closure relations. (Cohen-Tannoudji, Chapter 2)

Lecture 5 [1] Mathematical Tools of QM. Dirac notation: ket, bra. Dual space. Discrete basis, continuous basis. Orthonormality relations, closure relations. (Same as last lecture, but in Dirac notation.) (Cohen-Tannoudji, Chapter 2)

Lecture 6. [1] Mathematical Tools of QM. Change of basis using Dirac notation: discrete/continuous basis. Matrix elements of operators. Psi in r basis, p basis: change of basis here is a Fourier transform. Eigenvalue equations and observables. Degenerate, non-degenerate eigenvalues. Orthogonality of eigenspaces belonging to different eigenvalues. Hermitian operators have real eigenvalues. The concept of "observable": e.g., the projection operator. (Cohen-Tannoudji, Chapter 2)

Lecture 6B. [1] Mathematical Tools of QM. Simultaneous diagonalization of two Hermitian operators: non-degenerate case; degenerate case. Block diagonal matrix. Functions of operators: differentiation, integration. Two useful, easy theorems. (Cohen-Tannoudji, Chapter 2; Shankar)

Lecture 7. [0.5] Mathematical Introduction. Some operators in infinite dimensions: X and K operator matrix elements in X and K bases. Commutation operator [X,K]. Hermiticity in infinite dimensions: necessary and sufficient conditions. (Domain of unbounded operators.) NONEXAMINABLE: Meaning of diagonalization of Hermitian operators: normal modes/stationary states. Example: two masses on three springs in one dimension. Example: string clamped at both ends. (Shankar p. 46-54, 57-73.)

Lecture 7B [1] Postulates of Quantum Mechanics (in-depth reprisal of Lecture 4). Quantum state. Reduction (collapse) of the wave packet; role of the projection operator; probability of results of measurement. [Time evolution of a system. (Susskind2 4.12, 4.13)] Quantization rules. Compatible, incompatible observables and the commutator operator. Imprecise measurements. (Cohen-Tannoudji p.213-225; 231-236; 263-266)

Lecture 8. [1] Postulates (cont'd) and Simple Problems in One Dimension. Why is a quantum ensemble necessary? (Shankar p. 125-127) Expectation value and uncertainty (Shankar p. 127-129). Example 4.2.4: Gaussian wave fn. (Shankar p. 134-141) How to extract experimental information from a wave function: probability that a particle has position between x and x+dx; probability that a particle has momentum between p and p+dp; uncertainty in position; uncertainty in momentum. Recipe for solving quantum mechanical problems: the propagator. Space-time propagator for a free particle in one dimension (Shankar p. 151-154).

Optional Lecture 8B. Simple Problems in One Dimension (cont ’ d). Time-evolution of the Gaussian wave packet. NONEXAMINABLE: The probability current. Wave packet incident on a potential step (1D scattering). (Shankar Chapter 5)

Lecture 9. [0.5] The Classical Limit and Simple Harmonic Oscillator in X-basis. (Revision of Fourier transforms. Midsemester exam up to here.) Ehrenfest ’ s Theorem (Shankar Chapter 6 or Susskind2 4.9, 4.10). Why is the motion of a particle in the quantum regime different to its motion in the classical regime? Under what conditions do the classical equations of motion hold? (Shankar Chapter 6) NONEXAMINABLE: Solution of the linear SHO in the X basis (Shankar Chapter 7).

Lecture 10. [1] SHO in the Energy Basis. Ladder operators: creation and annihilation operators. Number operator. (Shankar Chapter 7 or Susskind2 Chapter 10.)

Lecture 11. [0.5] Path Integral Approach. Simplistic introduction: calculating the propagator using Feynman's path integral approach. The space-time region of coherence. (Shankar Chapter 8 or Susskind2 9.8 for an elementary description.) NONEXAMINABLE: Equivalence to the Schroedinger equation. The propagator for systems with potential energy of a certain, useful general form is relatively easy to calculate using the path-integral approach. Why? (Shankar Chapter 8)

Optional Tutorial Lecture 11B. Path Integral Approach (cont ’ d). We complete optional topics not finished in Lecture 11.

Lecture 12. [0.75] Heisenberg Uncertainty Relation. A purely “ mathematical ” derivation. (Susskind2 5.3-5.7, 8.5) Another purely “ mathematical ” derivation that exposes conditions for minimum uncertainty. The minimum uncertainty wave packet is a Gaussian. Application to estimation of ground state energy of hydrogen atom. (Shankar Chapter 9) NONEXAMINABLE: The standard U.R. gives the wrong result for certain pairs of canonically conjugate observables. Why? Domain of unbounded operators revisited. Derivation of a more generally applicable U.R. (Chisolm, American Journal of Physics 2001) following a simple rule.

Lecture 13. [1] Systems with 2 or more identical particles. Pauli Exclusion Principle follows from a basic experimental fact. (Gottfried) Bosons, fermions. Symmetry or antisymmetry of the TOTAL wave function. Fermionic and bosonic spatial or spin wave functions. Normalisation of state vector. Interference. Combining quantum systems: direct product spaces. Quantization in 1, 2, 3 dimensions (separable partial differential equations). (Shankar Chapter 10)

Lectures 14, 15. [2] Combining Quantum Systems, Entanglement, Correlation. (Susskind2 Chapters 6,7) We explore entanglement and correlations in a 2-qubit system. Density matrix (Shankar), reduced density matrix (Merzbacher, Gottfried).

教科書　Textbook

1. Shankar, R., 1994, Principles of Quantum Mechanics, 2nd ed., Kluwer Academic/Plenum.

2. Susskind, L. and Hrabovsky, G., 2013, The Theoretical Minimum [Classical Mechanics], Basic Books.

3. Susskind, L. and Friedman, A., 2014, Quantum Mechanics: The Theoretical Minimum, Basic Books.

4. Cohen-Tannoudji, C., Diu, B., Laloe, F., Quantum Mechanics, Wiley, 1991. Chapters 2 and 3 are required in the lectures. They complement, and at times supersede, the treatment in Shankar.

参考書　Recommended reading

1. Goldstein, H., Classical Mechanics, 2nd Edition.

2. Feynman, R.P., Leighton, R.B., Sands, M., 2011, Feynman Lectures on Physics (Volume 3), Basic Books. (Highly recommended introductory book on quantum mechanics.)

3. Merzbacher, E., Quantum Mechanics, 3rd Ed., Wiley, 1998. (A great teacher of QM.)

4. Gottfried, K. and Yan, T.-M., 2004, Quantum Mechanics: Fundamentals, Springer.
(Advanced reference. Excellent treatment of identical particles and PEP.)

5. Kreyszig, E., 1989, Introductory Functional Analysis with Applications, Wiley Classics. (Clear introduction to infinite dimensional Hilbert space, inner product spaces, spectral theory of linear operators, self-adjoint linear operators, etc. Read this - particularly the latter chapters on unbounded operators - if you want to clear up some mathematical concepts encountered in Shankar.)

連絡方法　Contact method

その他　Remarks
*See Course List and Graduation Requirements for your program for your enrollment year. • Students must be willing to work hard to achieve a good, internationally competitive level. • Alternatively, students who wish to just pass the unit may choose to work through the two books by Susskind, which cover more or less the same topics (except for identical particles) in a far more elementary way, and submit a reasonable number of solved problems. The books by Susskind are written for people who have not previously learned physics.