**Syllabus: Quantum Mechanics I**

**Fall 2024**

**Instructor:**  Dan Boyanovsky, 208 Allen Hall, ph: (412)-624-9037, e-mail: [boyan@pitt.edu](mailto:boyan@pitt.edu)

**Objectives:**  The objectives of the class are to obtain a solid, deep and broad knowledge of Quantum Mechanics. The class focuses on the fundamental aspects and discusses various applications from condensed matter, particle physics and astrophysics, emphasizing conceptual and calculational frameworks, discussing in depth the mathematical background and physical principles.

**Prerequisites**: Undergraduate QM, at the level of 1000 courses in our curriculum, Mathematical Methods and undergrad electromagnetism and classical mechanics.

**Content:**  Brief history: QM emerges as a clash between observations and theory. Waves and uncertainty: The Schroedinger eqn. Bohr-probabilistic interpretation. Continuity eqn. Stationary states. Poisson Brackets 🡪 commutators. Superposition pcple. Wave packets. QM in 1-d: orthogonality and completeness. Wells and barriers, tunneling. Symmetries. Bound and continuum states. Mathematical framework: the Sturm-Liouville problem and linear vector spaces: Hilbert space. Hermitian operators and their spectrum. Commutation relations and representations. Momentum-space and energy-time uncertainty relations. Schroedinger and Heisenberg pictures. Matrix representations. Symmetries: introduction to Group Theory: Lie groups and Lie algebras, Generators. Abelian and Non-Abelian groups. Symmetries and conserved quantities. Discrete symmetries: crystals Bloch Theorem and Bloch functions. The origin of bands. Supplement: the Kronig-Penney model of bands. The 1-d Harmonic oscillator: wave mechanics, Fock representation: raising and lowering operators, matrix mechanics. Quan. Stat. Mech. Coherent states. 3-D: central force problems: Angular momentum: quantization. Radial equations and effective potentials. The Hydrogen (1 electron) atom: bound states, Balmer series and continuum spectrum: the effect of long range. Angular Momentum: orbital and spin: Rotations as a non-abelian group (SO(3)), angular momentum operators as generators, Lie algebra and representations. Supplement: the Lenz vector, harmonic oscillators and the bound states of the H-atom. Spin ½: Stern-Gerlach experiment: spinors and SU(2). Addition of angular momentum: irreducible representations and Clebsh-Gordan coefficients: entangled (Bell) states. App: Spin-orbit coupling. Wigner-Eckardt Theorem and selection rules. Time independent perturbation theory: non-degenerate and degenerate cases, examples: spin-orbit, fine and hyperfine structure of the H-atom: the 21 cm astrophysical line. Zeeman and Paschen-Back effects in magnetic fields. The Van-der-Walls interaction between atoms. Non-perturbative methods WKB: connection formula and bound state quantization conditions. App: Gamow’s theory of alpha decay and thermonuclear fusion processes in stars. Dynamics: two level systems, Larmor precession of spins: classical and quantum, basics of NMR and spin resonance: pi pulses and population inversion. App: the physics of neutrino oscillations. Time dependent perturbation theory: interaction picture and Dyson series. Harmonic perturbations: comparison to exact treatment. Transition rates. Fermi’s Golden rule and exponential decay. App: a model for decay of a two level system.

**Suggested Textbooks**: The material is standard and there are several excellent textbooks:

**Lectures on Quantum Mechanics** by G. Baym,

**Modern Quantum Mechanics** by J. J. Sakurai,

**Principles of Quantum Mechanics** by R.Shankar,

**Quantum Physic**s by M. Le Bellac,

**Quantum Mechanics: Fundamentals** by K. Gottfried, T-M. Yan

and various other good books. I will borrow freely from many books and will not adopt a particular one.

**Class notes will be shared**: I will send by e-mail the lecture notes for the class two days in advance, so you have an opportunity to study the material prior to class which will cover the details in more depth and expand upon the notes. The notes are NO substitute for coming to class, they are a complement to the class. **THE NOTES ARE ONLY FOR YOUR PERSONAL USE, NOT TO BE SHARED OR DISTRIBUTED, THEY ARE PROTECTED BY INTELLECTUAL PROPERTY RIGHTS.**

**OFFICE HOURS: Monday, Wednesday,Friday 3:30 pm -🡪 4:30 pm in my office: 208 Allen Hall. There will be a tutor available, TBA.**

**I will also respond to questions by e-mail within 24 hours. If needed we can meet via zoom at a time of mutual convenience.**

**Suggestion to make the most out of the course: 1) study the notes prior to class, 2) come to class, annotate the questions in the notes that need more explanation, and during class focus on these, THE NOTES ARE NO SUBSTITUTE FOR THE CLASS, THEY COMPLEMENT THE CLASS, 3) go back to the notes and re-study them in view of what I covered in class, 4) do the homework, this is the only way to actually learn!!. Try to do the homework on your own rather than in groups to avoid ``groupthink’’.**

**Homework: every week I will assign a set of 4 problems on the material covered during the week. Doing the homework is an important part of the learning experience, and the only way to actually understand the material.**

**Homeworks will be sent by PDF on Fridays, they are due back in PDF and compressed format (files larger than 5Mb will be returned for compression!) by the following Friday no later than midnight. No grace period is allowed and no late homework will be accepted**.

**Exams: there will be a one week take home midterm and a one-week take-home final exam. THE EXAMS MUST BE INDIVIDUAL, I RESERVE THE RIGHT TO SUMMON TO AN ORAL EXAMINATION IF IN DOUBT.**

**Grade: The final grade is obtained as follows: (1/3)x (average of homework)+ (1/3)xMidterm+(1/3)xFinal**