

# ADVANCED QUANTUM PHYSICS

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**Review of Quantum Physics:** Postulates of quantum mechanics, operator methods, time dependence. Solutions to Schrödinger's equation; quantum well, simple harmonic oscillator. Angular momentum and spin, matrix representation, identical particles.

**Methods of Approximation:** Variational method, ground state energy and eigenfunction, helium atom, excited states. Revision of hydrogen atom, Born-Oppenheimer approximation,  $H_2^+$  ion, molecular orbitals,  $H_2$  molecule, ionic and covalent bonding. Time-independent perturbation theory; harmonic oscillator, helium atom, Stark effect in a quantum well. Degenerate perturbation theory; Stark effect in hydrogen, electrons in a one-dimensional solid, coupled quantum wells.

**Relativity and Magnetic fields:** Hamiltonian in an electromagnetic field, magnetic vector potential, gauge invariance of Schrodinger equation, phase of wavefunction, the Aharonov-Bohm effect, quantization of magnetic flux. Relativistic quantum mechanics; the Dirac equation, spin, anti-particles, discovery of the positron, gyromagnetic ratio, spin-orbit interaction, relativistic corrections to hydrogen atom. Particle in a uniform magnetic field, orbital and spin magnetic moments, Zeeman effect, Larmor precession. Landau Levels, Shubnikov-de-Haas effect.

**Transitions:** Two-state system, Rabi oscillations, Magnetic resonance. Time-dependent perturbation theory, Fermi's golden rule, scattering and the Born approximation. Radiative transitions in a semiclassical electromagnetic field, electric dipole approximation, Einstein's A and B coefficients, selection rules. Quantization of the electromagnetic field, number states, single photon source, spontaneous and stimulated transitions. Coherent states. Lasers; cavity, rate equations, population inversion, quantum cascade laser.

**Atoms:** Real single electron atoms; effect of nucleus, spin-orbit interactions, relativistic effects, quantum electrodynamics. Multi-electron atoms; central field approximation, exchange interactions, periodic table, artificial atoms, LS coupling, Hund's rules. Zeeman effect; strong and weak fields.

**Quantum Information\*:** Quantum bits, Bell states, quantum gates, entanglement and teleportation. Quantum computation and cryptography.

[\* = non-examinable]

## BOOKS

*Quantum Physics*, Gasiorowicz S (2nd edn Wiley 1996, 3rd edn Wiley 2003)

*Quantum Mechanics*, Rae A I M (4th edn IoP 2002)

*Quantum Mechanics*, Bransden B H and Joachain C J (2nd edn Pearson 2000)

*Molecular Quantum Mechanics*, Atkins P W and Friedman R S (3rd edn OUP 1997)

*The Physics of Atoms and Quanta*, Haken H, Wolf H C (6<sup>th</sup> edn Springer 2000)

*Quantum Optics; An Introduction*, Fox A M (OUP 2006)

*Problems in Quantum Mechanics*, Squires G L (CUP 1995)