

# PHY202 – Quantum Mechanics

## Topic content and examinable material:

(N/E – means non-examinable)

**Note:** all the examples done in class and all the HW, problem class and tutorial problems are also examinable.

### Topic 0: Mathematics for Quantum Mechanics

Examinable only in the context of solving problems for subsequent topics

### Topic 1: Early days of Quantum Mechanics

Qualitative summary from 1st year only (revise your 1st year notes!) - otherwise N/E

- brief history, from classical to quantum physics
- black body radiation, UV catastrophe, Planck's solution
- the photoelectric effect
- wave-particle duality
- waves as particles: Compton scattering
- particles as waves: double slit diffraction
- line spectra and atomic structure, Bohr's model of H atom
- Heisenberg uncertainty principle (HUP), first encounter

### Topic 2: The Schrödinger equation

- the time-dependent Schrödinger eq (TDSE)
- general properties of the TDSE (diff eq, linear)
- a wavefunction  $\Psi(x, t)$  and its general properties
- a probabilistic interpretation of  $\Psi(x, t)$
- general physical properties and boundary conditions of the wavefunction
- normalization of  $\Psi(x, t)$  to unity
- the time independent Schrödinger eq (TISE) and its derivation from the TDSE
- stationary states  $\Psi(x, t) = \exp(-i/\hbar Et)\psi(x)$

### Topic 3: The Infinite Potential Well (IPW)

- $V = 0$ ; solution: plane waves moving in +ve and -ve  $x$  direction
- the infinite potential well from  $x = 0$  to  $x = L$  and its solution
- quantized energy levels
- normalized wavefunctions
- HUP for infinite potential wells
- the symmetric IPW
- symmetries of the wavefunctions; even and odd parity

### Topic 4: The Finite Potential Well (FPW)

- the quantum well
- the symmetric FPW and its solution
- even parity solutions
- odd parity solutions
- comparison with the infinite potential well
- quantum tunnelling
- general properties of well-type potentials

### Topic 5: Operators and Eigenstates

- the Hamiltonian  $\hat{H}$
- the TISE  $\hat{H}\psi(x) = E\psi(x)$  as an eigenvalue eq.
- linear operators and their eigenvalue eqs.
- general properties of eigenfunctions (an orthonormal and complete set)
- eigenfunctions of the Hamiltonian
- linear expansion of a wavefunction  $\phi(x) = \sum_n a_n \psi_n(x)$
- operators and observables
- operators of KE  $\hat{T}$ , PE  $\hat{V}$ , total energy  $\hat{H}$ , momentum  $\hat{p}$ , position  $\hat{x}$ , parity  $\hat{P}$
- discussion of states of definite and undefined parity
- plane waves as momentum eigenstates

- symmetric and antisymmetric states as eigenfunctions of parity

### Topic 6: Measurements in QM

- the meaning and the properties of the coefficients  $a_n$
- measurement of energy, possible outcomes and associated probabilities
- measurement and a collapse of the wavefunction
- average values of observables in QM
- an average value of an observable for a general wavefunction
- an average value of an observable in terms of its own eigenstates
- an average value of energy  $\langle E \rangle = \sum_n |a_n|^2 E_n$  for  $\Psi(x) = \sum_n a_n \psi_n(x)$
- fluctuations
- simultaneous measurements and the HUP
- $\Delta\lambda = 0$  for eigenstates of the observable  $\lambda$
- a commutator of two operators
- simultaneous measurements and relation to commutators
- the HUP for position and momentum  $[\hat{x}, \hat{p}] = i\hbar$
- (momentum wavepackets - a continuous momentum case – N/E)
- (Gaussian wavepackets – N/E)
- (particle localization in position  $x$  and momentum  $p$  – N/E)

### Topic 7: The Linear Harmonic Oscillator (LHO)

- motivation – N/E
- a brief review of the classical LHO – N/E
- the eigenstates of the quantum LHO
- properties of the wavefunctions and probability densities
- the Correspondence Principle

### Topic 8: Time dependence in QM

- time dependent bound states
- pure (or, stationary) states  $\Psi_n(x, t) = \exp(-i/\hbar E_n t) \psi_n(x)$

- mixed states  $\Psi(x, t) = \sum_n a_n \Psi_n(x, t)$
- a superposition of two pure states
- a superposition of two pure states of the LHO, probability density and  $\langle E \rangle$
- a superposition of two pure state
- measurement in time dependent cases

### **Topic 9: Quantum propagation**

- (wavepacket propagation – N/E)
- quantum mechanical currents
- the continuity equation and its physical meaning
- properties of currents
- current for stationary states and real wavefunctions
- current for plane waves
- classical potential steps and barriers – N/E
- QM potential step and beam incident on it
- incident, reflected and transmitted currents
- the probability of reflection  $P_R$  and the probability of transmission  $P_T$
- potential barrier and beam incident on it ( $P_T$  without derivation)
- the HUP for time and energy
- examples of quantum tunnelling in nature

### **Topic 10: The Schrödinger Eq. in 2 and 3 dimensions**

- The Schrödinger Equation in 3 dimensions
- degeneracy of energy states
- the 2-dim IPW and degeneracy

### **(Topic 11: Puzzles and Paradoxes in Quantum Mechanics – N/E)**

### **Topic 12: First order time-independent perturbation theory – N/E**