Quantum Mechanics Learning goals - working document.

The goals below should not be considered a complete list "spanning" a quantum course. They were merely the topics which received the most attention at our Fall 2017 Quantum learning goals faculty workshop in Boulder. Largely, participants focused on topical-level goals.
For a list of course-level meta goals see e.g. the CU Boulder learning goals at
https://physicscourses.colorado.edu/phys3220/phys3220_fa16/course_goals.html

All goals should be preceded by: "Students should be able to…"

1. Quantum states:

A. …calculate normalization constants for quantum states.
B. …recognize the difference between an overall phase and a relative phase and the effect that has on measurement outcomes.
C. …convert states between different bases (e.g. x-, y-, z-, or energy bases for spin, or between x and Energy, or x and p for position).
D. …write the time evolution of a quantum state, given the state at t=0 and the Hamiltonian. (first-level version: state given in energy eigenbasis; second-level version: state not given in energy eigenbasis)
E. …distinguish between energy eigenstates, superposition states, and mixed states.

2. Observables:

A. …determine the possible set of values that could result from a measurement of a given observable (i.e., calculate eigenvalues and recognize they represent possible measurement outcomes)
B. …calculate the probability of a measurement outcome given a quantum state (including time dependence when relevant).
C. …calculate expectation values for a given observable and given quantum state using multiple methods when appropriate (including time dependence when relevant).
D. …distinguish between expectation values, allowed values, most probable value.
E. …calculate the uncertainty for an observable given a quantum state.
F. …determine the resulting quantum state after a measurement (e.g. after a spin is measured to be up in the x-direction).
G. …determine whether two observables can be simultaneously determined.

3. Hamiltonian and the Schrodinger Equation:

A. …distinguish the time dependent Schrödinger equation from the energy eigen-equation (aka "time independent Schrodinger equation").
B. …write the appropriate Hamiltonian for a given physical context.
C. …use the energy eigenvalue equation (aka "time independent Schrödinger equation ") to solve for the energy eigenstates and/or eigenvalues for a given system.
D. …identify and apply boundary conditions in a 1-D piecewise-constant potential.
E. …sketch a qualitatively correct wave function given a 1D potential (attending to features like the number of nodes, the sign of the curvature, the relative wavelengths and amplitudes).

Continued…

4. Formalism and mathematics:

A. …rewrite any complex number between rectangular and polar form.
B. …distinguish operators, eigenfunctions (or eigenvectors or eigenstates), and eigenvalues.
C. …find the eigenvalues and eigenvectors of given operators.
D. …use the technical language of QM correctly (for example: basis, bra and ket, commutator, expectation value, Hamiltonian, Hermitian conjugate, Hilbert Space, operator, probability, projection, uncertainty,…).
E. …use the commutator to determine if an observable is a conserved quantity.
F. …distinguish between applying an operator to a state and making a measurement.

5. Widely considered important (but harder to operationalize or directly test)

A. …connect mathematical results to physics[1]
B. …use postulates of quantum mechanics to guide problem solving.
C. …formulate strategies to solve well-defined problems (regardless of whether they can perform the calculation).
D. …be able to move between different representations (for example: bra-ket notation, matrix notation [explicit and/or abstract matrices], wave functions, graphical visualizations, computer code, …)
E. …recognize the limits of classical theory and where we need to assume QM behavior.

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[1] Math/Physics connections is a common, generic course-level learning goal in any physics course. Here were some concrete examples of math/physics connections in QM:
- students can defend the functional form or behavior of spatial wave functions based on classical intuitions or physical requirements
- students can give qualitative arguments for limiting behaviors of transmission and reflection formulas based on physical or classical intuitions.
-students can productively connect spin-precession formalism to classical or physical top motion, (or, interpret various mathematical limits of Rabi's formula to more classical pictures of classical magnets in fields)
-students can make useful analogies of spin ½ formalism to more classical photon polarization measurements

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