

Learning Goals for UBC PHYS 250, *Introduction to Modern Physics*, Summer 2009

This list may be modified slightly as the Term progresses and we realize there are things we expect you to learn that we forgot to list, or there are things we decide you need not learn in this course.

Course level goals

general--

1) A bunch of old curmudgeon engineers complain to the engineering curriculum committee that quantum mechanics is a waste of time for any engineering student to take, claiming that regular engineers only work on things that only use classical (nonquantum) physics, and quantum physics is so weird it makes no sense and it is probably wrong anyway. You will be able to convince the engineering curriculum committee that the ideas of quantum physics are true and that it is useful for engineers to know about them.

2) You will: see quantum mechanics as the most fascinating physics you have encountered, and see it as a way to understand the world at a level you never imagined possible; recognize and be able to describe how quantum mechanics is visible in world all around you; recognize that physics required a major paradigm shift to advance its understanding of nature to the atomic size scale and smaller, but that the behaviour at that size also determines all macroscopic properties. This paradigm shift also involves accepting both the totally non-intuitive quantum ideas, and an approach to understanding the physical world by the use of mathematical models that match experiment, and then figure out what math implies, rather than in the reverse order has had previously been used. You will confront this intellectual paradigm shift and become at least partially comfortable with it.

3) You will learn how to learn more effectively. You will understand the value of and use in your learning of: collaboration with peers, improvement in metacognitive skills, effortful study and practice, need for focused intense extended study time, and repeated recall and application for assessment. You will regularly use sense-making and explanations as part of solving physics problems, and be able to argue as to the value of doing this.

Specific content goals

(“Quantitative” means you will be able to describe in terms of specific numbers, and so will usually involve calculations. “Qualitative” means using general reasoning and definitions, but not calculating any numbers.)

I. Quantum Mechanics

1. Modeling of physical systems.

Be able to describe a physical situation that would correspond to simple potential energy curves. Given a simple physical system, be able to draw the relevant potential energy curve needed to model dynamical behaviour. Explain why models are useful in physics.

2. Light as a Particle- why believe idea that there are particle and wave like properties to objects, role of probability in this interpretation

- Write down the mathematical description of a classical electromagnetic wave, and relate the terms in the expression to the velocity, wavelength, and frequency of the wave.

- Be able to describe how the energy in a classical EM wave depends on the amplitude of the field, and describe what happens when an EM wave is absorbed by a material if the wavelength is long enough that it behaves classically.
- Design an experiment to show that something behaves as a wave.
- Qualitatively describe what is measured in the photoelectric effect experiment and explain how this implies a quantum picture of light, including explaining what results the classical interpretation of light would predict for this experiment.
- Quantitatively analyze photoelectric data to deduce the relationship between energy of photons and frequency of light and predict how the emission of electrons will change if color of light, type of metal, or voltage of the metal is changed.
- Be able to design an experiment for determining the composition of an unknown pure metal based on the photoelectron effect.
- Be able to explain the essential role of the quantization of light as demonstrated by the photoelectric effect in the operation of a photomultiplier tube, a solid state photodetector such as used in motion sensors, and the human eye. (Essentially all sensitive detectors of light.)
- In two slit interference pattern produced by light, relate the single particle detection of photons to the interference pattern from light beams.

3. Electrons as waves and particles

a. emission and absorption of light by isolated atoms

- Explain how the discrete colors produced by neon signs, mercury and sodium street lights, and other discharge lamps rule out Rutherford's model of the atom as like a miniature solar system with electrons orbiting the nucleus.
- Relate the colors of light produced by a discharge lamp to energy levels of the electron in the atoms in the lamp.
- Be able to explain why such light sources are so much more efficient than incandescent light bulbs.
- List the basic assumptions of the Bohr model of the atom and explain how those assumptions are consistent with the light emitted by a hydrogen discharge lamp.
- Be able to provide a basic design for a gas laser, giving the basic components and qualitative requirements for it to operate.

b. electrons as waves

- Explain the interpretation and significance of the pattern observed when a beam of electrons is sent through two very closely spaced slits and detected on a screen behind them.
- Explain what was observed in the Davisson-Germer experiment and how these observations support the interpretation of electrons as waves.
- Sketch out the design for an experiment to use an electron beam to measure the spacing between atoms in a clean crystal. Say what the data will look like, in quantitative terms how to extract get the atomic spacing from the data, and justify to someone who does not know QM why your data and analysis is actually measuring the atomic spacing. Suggest experiment that could verify your justification.

4. Electrons as probability waves.

- Given a particle description of an electron or photon, relate that to an equivalent wave description, and vice-versa.
- Calculate the Broglie wavelength of a particle given the momentum, and vice-versa. Make quantitative predictions for what will be detected on screen behind two closely spaced slits when particles of known mass and energy are shot at the slits.
- Describe the double-slit experiment for light and electrons and explain why the interference pattern is different depending on whether or not a measurement is made as to which slit the photon/electron passes through
- Analyze the implications of the results of the double slit experiment in terms of the description of the position of an initial electron
- Explain what is meant by the eigenstates of an electron, in terms of the energy, position and momentum, when the electron is both free and when it is confined in some potential energy well.
- Write down the mathematical description of the wave functions for position and momentum eigenstates of free electrons.
- Explain how a wave function can be used to describe a general complex superposition of all position eigenstates
- Calculate the probability for finding a particle in a given region of space from its wave function.
- Qualitatively relate the shape of the wave function to the relative probability of finding the particle at different positions in space, and in different momentum ranges.
- Qualitatively relate the shape of the wave function to the kinetic energy of a particle at different locations in space
- Define an expectation value and be able to predict what will be observed when one measures the position or energy of an electron that is described by a known wave function.
- Argue why it is plausible that one can describe any function as a suitable superposition of sinusoidal functions
- Argue how the description of a particle in terms of a wave function implies the Heisenberg uncertainty principle, and be able to use this principle to calculate the minimum possible uncertainty in measurements of position and momentum of particles.

5. Schrodinger equation and potential energy wells

- Explain why a very deep square well potential is a crude but useful model for a variety of physical systems, including electrons in atoms or wires.
- Calculate the possible energy levels and normalized wave functions and probability distributions for an electron in a very deep square well potential of arbitrary width in one dimension. Be able to use these distributions to predict the results of measurements of these quantities for an electron.
- Explain general method for how to find allowed energies for an electron or atom in any shape potential energy well, although not carry out the detailed calculations required for obtaining values for those energies.
- Calculate how the current in a scanning tunnelling microscope (STM) depends on the distance between the probe and the surface. Explain how an STM is able to obtain a measurement resolution of less than one atomic diameter.

6. Atomic Structure and interactions between light and atoms

- Write down the Schrodinger equation for the electron in a hydrogen atom
- Remember the basic characteristics and quantum numbers that describe the solutions to the Schrodinger equation for a hydrogen atom.
- Explain how the Schrodinger equation predicts that different types of atoms will be different colours and that it will require different amounts of energy to remove an electron.

7. Conductivity of electrons in materials

- Given the conductivity of a material, predict the energy distribution of the electrons in the material.
- For an unknown material, be able to analyze whether it is a conductor, insulator, or semiconductor, and then predict what electron energy distribution it must have.
- Describe the energy distribution the electrons need to have in order to produce a desired conductivity of a material.
- Qualitatively design a semiconductor diode that will only allow current to flow in one direction, and will produce light (i.e. an LED).

II. Special Relativity

1. Puzzles from Electromagnetism

- Give simple examples from electricity and magnetism that show that either the principle of relativity or some basic notions of distance, time, and velocity must be abandoned

2. Einstein's Resolution

- Argue how the experimental evidence implies that the velocity of light is always independent of the motion of the source or of the observer
- State Einstein's postulates of special relativity
- Explain how an given observer can set up a coordinate system for making measurements of time and position
- Show how Einstein's postulates imply that observers at large relative velocities will not agree on distances, time intervals or whether two events are simultaneous
- Describe qualitatively the meaning of length contraction and time dilation
- Calculate the lengths and times differences that an observer will measure, accounting for length contraction and time dilation.
- Relate the measurements of observers moving at arbitrary relative velocities using the Lorentz transformation formulae
- Calculate the observed velocity of an object in a new reference frame given the velocity in the old frame and the relative velocity of the two frames

3. Relativistic Energy and Momentum

- Argue why classical formulae for momentum and energy must be modified to make sense physically at high velocities
- Write down the relativistic formulae for energy and momentum and use them to solve simple mechanics problems
- Give evidence for the equivalence between energy and mass and explain the implications