

Modern Physics – Exam 2 – Learning Goals

- Know the predictions of classical EM wave and photon models for the photoelectric effect.
- Know the definition of the work function, and its relationship with the energy of the incoming photons and the initial kinetic energy of the ejected electrons.
- Be able to graph the following observed relationships in the photoelectric effect, explain what they mean in words, and how they support a particle model of light:
 1. Current vs. Frequency
 2. Current vs. Intensity
 3. Current vs. Voltage
 4. Stopping Voltage (or equivalently Initial KE) vs. Frequency
- Understand how the intensity of a beam of light (including the definition of intensity) is related to frequency and amplitude for both photons and EM waves.
- Understand the relationship between atomic energy levels, atomic energy level diagrams, and observed atomic spectra in a discharge lamp.
- Know the three important characteristics of laser light that distinguishes it from the light from an incandescent bulb (or the sun).
- Understand the differences between photon absorption, spontaneous emission, and stimulated emission, and the conditions required for each to take place.
- Know how many atomic energy levels are needed to create laser light, the relevant features of those energy levels, and be able to explain why.
- Know the two assumptions of the Bohr model and be able to apply those assumptions in order to find the energy levels and orbital radii of the Bohr model for hydrogen and single-electron atoms.
- Know the definition of the deBroglie wavelength, and how this leads to an improvement on the Bohr model.
- Understand (qualitatively) the behavior of magnetic moments in magnetic fields (uniform and non-uniform), and the possible outcomes of Stern-Gerlach measurements for both random and definite incoming atomic states.
- Know the relationship between the incoming state of an atom, the orientation of a SG-analyzer, and the probability for a measurement outcome along that axis given the incoming state.
- Understand the relationship between the orientation of a SG-analyzer and the outgoing state of the atom.
- Understand how to use compound probabilities (e.g., whether to add or multiply two probabilities to find the total probability).
- Understand how to normalize probability densities, and use them to calculate probabilities and average values of a variable.
- Be familiar with the terms *locality*, *realism*, *hidden variables* and *completeness*; and be able to discuss the difference between *classical ignorance* and *quantum uncertainty*. Understand the arguments for and against a *Local Realist* interpretation of quantum mechanics.

- Understand the role of *quantum entanglement* in relating the measurement outcomes between two distant analyzers on an entangled pair (of photons or atoms).
- Be familiar with the experimental setup for the three single-photon experiments, and how each type of setup leads to which type of observed behavior for photons (particle or wave), and be able to explain in what sense photons are behaving as wave or particle in each type of experiment.
- Understand the relationship between wavelength and the maxima and minima of the interference pattern in a double-slit experiment with either photons or matter particles.
- Know the relationship between the wave function and the probability density for where a particle might be located when observed.
- Be familiar with how the addition of many plane waves can combine to form a wave packet, and the relationship between the uncertainty in the position or momentum for a plane wave and a wave packet.
- Be able to relate the ideas of *Complementarity* and wave-particle duality to the Heisenberg uncertainty principle.

For students who would like an alternative perspective on the topics covered in the lectures and homework, there are the following relevant sections in Thornton and Rex (Modern Physics for Scientists and Engineers, 3rd Edition):

- 3.3 – Line Spectra – pp. 92-95
- 3.6 – Photoelectric effect – pp. 103-111
- 3.7 – X-Ray Production – pp. 111-113
- 4.4 – The Bohr Model of the Hydrogen Atom – pp. 141-147
- 4.5 – Success and Failures of the Bohr Model – pp. 147-150
- 4.7 – Atomic Excitation by Electrons – pp. 154-156
- 5.2 – deBroglie Waves – pp. 167-171
- 5.5 – Waves or Particles? – pp. 181-185
- 5.6 – Uncertainty Principle – pp. 185-189
- 5.7 – Probability, Wave Functions, and the Copenhagen Interpretation – pp. 190-193
- 7.4 – Magnetic Effects on Atomic Spectra – pp. 251-257
- 10.2 – Stimulated Emission and Lasers – pp. 342-351

A list of constants and equations that will be given with the exam:

Speed of light in empty space (c) $3.0 \times 10^8 \text{ m / s}$

Planck's constant (h) $6.626 \times 10^{-34} \text{ J} \cdot \text{s}$

$\hbar = \frac{h}{2\pi}$ $1.055 \times 10^{-34} \text{ J} \cdot \text{s}$

Charge of an electron (-e) $-1.6 \times 10^{-19} \text{ C}$

Mass of an electron (m_e) $9.11 \times 10^{-31} \text{ kg}$

Ground state energy of electron
in Hydrogen -13.6 eV

Mass of proton (m_p) $1.67 \times 10^{-27} \text{ kg}$

$hc = 1240 \text{ eV} \cdot \text{nm}$ $ke^2 = 1.440 \text{ eV} \cdot \text{nm}$ $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$

Representative wavelengths: Red (680 nm); Orange (610 nm);
Yellow (580 nm); Green (540 nm); Blue (470 nm); Violet (410 nm)

$1 \text{ ns} = 1 \times 10^{-9} \text{ s}$ $1 \text{ nm} = 1 \times 10^{-9} \text{ m}$ $1 \mu\text{m} = 1 \times 10^{-6} \text{ m}$ $1 \text{ mm} = 1 \times 10^{-3} \text{ m}$

Relativistic Energy-Momentum Relation:

$$E^2 = (pc)^2 + (mc^2)^2$$

deBroglie Relation:

$$\lambda = \frac{h}{p}$$

Energy of a photon:

$$E = hf$$