STUDY GUIDE FOR PART III: QUANTUM THEORY

INTRODUCTION:

Classical theory accounts for the results of many, many experiments and almost all of the everyday experiences. But there are several experiments that classical theory cannot account for. In fact, classical theory predicts results contrary to experimental evidence in these cases. As a result, a new theory had to be developed. Actually, there are two regions where classical theory breaks down. One place is where the speeds of particles become an appreciable fraction of the speed of light (which is about 670 million miles/hr). This area of breakdown led Einstein to his famous theory of relativity. The other place where classical theory breaks down is where the times and distances being considered become very small (smaller than 1 nm). This breakdown led to the quantum theory. In this part we consider the quantum theory. In Part IV we consider relativity. In Part V we consider an area that requires both quantum and relativity: nuclear physics and radioactivity.

The key to this and the next section is: a theory is only as good as the experiments it can account for and must be modified or abandoned in the face of experiments that contradict it.

Introduction to Quantum Physics

A. Blackbody radiation — S-40 to 43

1. the experiment — $P = \varepsilon\sigma A T^4$, $\lambda_{max} = b/T$; $\sigma = 5.67 \times 10^{-8}$ W/m²T⁴, $b = 2.9 \times 10^{-3}$ m*K
2. classical theory — $\Delta E \rightarrow 0$, UV Catastrophe
3. Planck's theory — $\Delta E = hf$

B. Photoelectric effect — S-44,45,46

1. the experiment
2. classical theory
3. Einstein's theory — $\Delta E = hf$, $KE = hf - W$

C. Compton scattering — S-47

1. the experiment
2. photon theory — $\lambda_{scat} = \lambda_{inc} + (h/mc)(1 - \cos(\theta))$

D. Atomic theory — S-48 to 53

1. size, structure of atom
2. atomic spectra, scattering experiments
3. Bohr's assumptions: L quantized — $L = n\hbar$ where $\hbar = h/2\pi$
4. Bohr's theory: E quantized, r quantized — $E = (-mk^2Z^2e^4/2\hbar^2)\times(1/n^2)$, $r = n^2\hbar^2/(mke^2)$

SUPPLEMENTARY PROBLEMS (S-):

40) Qualitatively graph the power output per wavelength vs. wavelength curve for a blackbody.

41) The sun's power output per wavelength vs. wavelength curve peaks at a wavelength of 500 nm.
(a) Assuming the sun is a perfect blackbody [a good but not perfect assumption], calculate its surface temperature. (b) What is the total power output of the sun? (R_{SUN} = 6.96 x 10^5 km, Area = $4\pi R^2$.)
(c) What is the Intensity (which = Power/Area) of sunlight at the Earth's distance from the sun? HINT: the energy spreads out over a sphere of area $4\pi R^2$.

42) Assume a person has a total body surface area of 1.9 square meters and an emissivity of 97%.
(a) At what wavelength does the radiation output peak? (b) How much radiation is emitted? (c) How much does the person absorb if the air temperature is 24°C?

43) What did the classical theory predict for blackbody radiation?

44) What was the key to Planck's solution to the blackbody radiation problem?

45) (a) What is the photoelectric effect? (b) State two cases where the classical theory failed to predict the actual results. (c) Explain how the photon theory accounts for these results.

46) The work function for Aluminum is 4.08 eV. (a) What is the cut-off frequency? (b) What is the stopping voltage for light of wavelength 250 nm (in the UV) ?

47) Is Compton scattering explained by the wave theory, the particle theory, by both theories, or by neither theory?

48) (a) What is the approximate size of an atom? (b) of a nucleus? (c) of an electron?
(d) How do we know this?

49) What is the weakness of classical theory in its attempt to describe atomic structures?

50) Describe Bohr's planetary model of the atom and give his two postulates.

51) (a) What is meant by the ground state of an atom? (b) Under what conditions is the energy of a planetary electron said to be zero?

52) (a) What is the ground state energy of the hydrogen atom?
(b) How much energy does it take to ionize the hydrogen atom?
(c) What would be the maximum wavelength of light that would be able to do this?
(d) What kind of photon is this (i.e., ultraviolet, visible, IR, etc.) ?
(e) How much energy would it take to excite a hydrogen atom in the ground state up to the n=3 state?
(f) What would be the possible decay schemes for this excited state, and the energy, wavelength, and color of the photons emitted in each scheme?

53) What is the radius of the electron's orbit in (a) the ground state, and (b) the n=3 state of hydrogen?

ANSWERS TO SUPPLEMENTARY PROBLEMS:

41) a) 5800 K; b) 3.9 x 10^{26} Watts; c) 1400 W/m^2 (standard value is 1350 W/m^2)

42) assuming T of skin = 35°C = 95°F: a) 9.6 mm; b) 940.4 Watts; c) 813.1 Watts.

46) a) 9.85 x 10^{14} Hz; b) 0.89 Volts.

52) a) -13.6 eV; b) 13.6 eV; c) 91.4 nm; d) UV; e) 12.09 eV;
f-1) $3 \rightarrow 1$, E = 12.09 eV, λ = 103 nm, UV;
f-2) $3 \rightarrow 2 \rightarrow 1$, E = 1.89 eV & 10.20 eV, λ = 658 nm & 122 nm, red & UV.

53) a) 5.53x10^{-11} m; (b) 4.77x10^{-10} m.

Quantum Mechanics

A. DeBroglie wavelengths $\lambda = h/p$ S-54,55,56

1. waves sometimes act like particles
2. particles sometimes act like waves

B. Uncertainty Principle $\Delta x \bullet \Delta p_x > \hbar$; $\Delta E \bullet \Delta t > \hbar$ S-57,58

1. don't know exactly where, when a wave is
2. don't know wavelength (momentum), frequency (energy) of particle

C. Schrodinger Equation S-59

1. operators
2. conservation of energy

D. Quantum numbers

1. particle in a box, 1-D
2. particle in a box, 3-D
3. harmonic oscillators

SUPPLEMENTARY PROBLEMS (S-):

54) a) If there is such a thing as the DeBroglie wavelength for matter, then we should be able to test it. Describe one experiment in support of the DeBroglie wavelength. b) Tell how the DeBroglie wavelength "explains" the Bohr assumption that $L=n\hbar$.

55) List three experiments that support the wave nature of light. List three experiments that support the particle nature of light.

56) List one experiment that supports the particle nature of matter. List one experiment that supports the wave nature of matter.

57) (a) What is the minimum uncertainty in the position of an electron if it is moving at 300 m/sec with an uncertainty of 0.01% ? (b) What is the minimum uncertainty in the position of a bullet of mass 2 grams moving at the same speed with the same uncertainty in the speed?

58) Demonstrate the Heisenberg Uncertainty Principle by describing one experiment that tries to measure those quantities that it relates.

59) Write Schrodinger's equation. Where does it come from?

ANSWERS TO SUPPLEMENTARY PROBLEMS:

57) a) 4 mm; b) $2\text{x}10^{-30}$ m.