Physical constants:

Planck's constant = 6.63×10^{-34} J·s

Boltzmann's constant = 1.38×10^{-23} J/K

speed of light = 3×10^{8} m/s

Bohr magneton = 5.79×10^{-5} eV/tesla

Electron charge = 1.6×10^{-19} C

Problem 1 (15%)

Let N_1 and N_2 be the number of atoms occupying the states with energies E_1 and E_2. A_{21}, B_{12}, and B_{21} are the Einstein's coefficients for spontaneous emission, upward transition, and stimulate emission between energy levels E_1 and E_2. h, k_B, c, T are Planck's constant, Boltzmann's constant, speed of light, and absolute temperature, respectively.

(a) (7%) Show that the energy density of the radiation in thermal equilibrium, $u(E_1-E_2)$ can be expressed as:

$$u(E_1-E_2)=\frac{C}{D\exp(hf/k_BT)-1}$$

Determine the C, D, and f in terms of N_1, N_2, E_1, E_2, A_{21}, B_{12}, B_{21} and the constants.

(b) (8%) Consider a hydrogen discharge tube operated at T = 300K. Calculate the ratio of the probability for spontaneous emission of the H_α line to that for stimulated emission numerically. The emission wavelength for H_α line is 656nm.

Problem 2 (10%)

Given three containers all at the same temperature, one filled with a gas of classical molecules, one with a fermion gas, and one with a boson gas. Assume the gas is ideal gas.

(a) (5%) Which will have the highest pressure? Why?

(b) (5%) Which will have the lowest pressure? Why?

Problem 3 (20%)

(a) (5%) Consider an electron in P state, what is the smallest angle between its angular momentum **L** and the z axis?

(b) (10%) Which of the following transitions in sodium do not occur as electric dipole transitions? Give the selection rule that is violated.

$4S_{1/2}\rightarrow 3S_{1/2}$　$4S_{1/2}\rightarrow 3P_{3/2}$　$4D_{5/2}\rightarrow 3P_{1/2}$　$4D_{3/2}\rightarrow 3P_{1/2}$　$5D_{3/2}\rightarrow 4S_{1/2}$

(c) (5%) The 3P states of sodium are doublets. The wavelengths resulted from the transitions from $3P_{3/2}$ and $3P_{1/2}$ states to the ground state are 589.0nm and 589.6nm, respectively. Calculate the magnetic field (unit: tesla) that the 3P

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electron in sodium experiences. Assume the magnetic field is parallel to the z axis.

Problem 4 (15%)

Consider a particle trapped in a one-dimensional box with infinitely high barrier at x=0 and L. Compute the following expectation values of the second excited states (n = 3).

(a) (5%) Position <x>.

(b) (5%) Linear momentum <p>.

(c) (5%) $\langle p^2 \rangle$.

Problem 5 (5%)

If the uncertainty in the position of a wave packet representing the state of a quantum system particle is equal to its de Broglie wavelength, how does the uncertainty in momentum compare with the value of the momentum of the particle?

Problem 6 (10%)

A beam of protons, each with kinetic energy 20MeV, approaches a step potential of 10MeV.

(a) (5%) What fraction of the beam is transmitted?

(b) (5%) If the particles are electrons instead, does the transmitted probability the same? Explain your answer.

Problem 7 (15%)

(BJT) For a bipolar junction transistor (BJT),

a. please draw a simplified structure of the "npn" transistor. (5%)
b. under the active-mode operation, please draw the profiles of minority-carrier concentration in the base, emitter and collector. (5%)
c. Please explain the "early effect" of a BJT. (5%)

Problem 8 (10%)

(Diode) Diodes can be used to realize rectifiers, which are commonly used in power circuits.

a. please draw circuit diagram of a "half-wave rectifier". (5%) (Hint : only power source, diodes and load resistors are used)
b. Please draw the input and output waveforms, assuming the diode resistance is much smaller than the load resistance, and a sinusoidal input waveform. (5%)

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