UNIVERSITY COLLEGE LONDON

EXAMINATION FOR INTERNAL STUDENTS

MODULE CODE : **PHAS4421**

MODULE NAME : **Atom and Photon Physics**

DATE : **30-May-07**

TIME : **10:00**

TIME ALLOWED : **2 Hours 30 Minutes**

2006/07-PHAS4421B-001-EXAM-18

TURN OVER

Answer any THREE questions

The numbers in square brackets in the right-hand margin indicate the provisional allocation of maximum marks per sub-section of a question.

Planck constant : $h = 6.63 \times 10^{-34}$ J s

Speed of light in a vacuum : $c = 3.0 \times 10^{8}$ m s^{-1}

Mass of a proton : $m_p = 1.67 \times 10^{-27}$ kg

Mass of an electron : $m_e = 9.10 \times 10^{-31}$ kg

Electronic charge : $e = 1.6 \times 10^{-19}$ C

Boltzmann constant : $k = 1.38 \times 10^{-23}$ J K^{-1}

[Part Marks]

1. Define oscillator strength (f_{ki}). [1]

   Give the oscillator balance equation for transitions between the levels $|\,i\rangle$ and $|\,k\rangle$ allowing for the degeneracy of the levels. [2]

   The transition probability A_{ki} for spontaneous emission from $|\,k\rangle \rightarrow |\,i\rangle$ is

   $$A_{ki} = \left[\frac{e^2 2}{3\varepsilon_0}\frac{\omega_{ki}^{\ 3}}{hc^3}\right]\left|\langle i|r|k\rangle\right|^2$$

   Derive an expression for A_{ki} involving the statistical weights of the levels. [4]

   Determine A_{ki} for a $^1P_1 \rightarrow {}^1S_0$ transition in the optical region at 300 nm where the total matrix element for the transition is $5a_0$. [4]

   What is the lifetime of the $^1P_1$ level? [2]

   Describe, with the aid of a diagram, a coincidence method for measuring atomic lifetimes. [4]

   If the excited atom in the $^1P_1$ level was confined in a cavity, explain how the cavity geometry can change the measured lifetime. [3]

2. A single point source S emits quasi-monochromatic light along two paths 1 and 2 defined by co-planar apertures P_1 and P_2. The light signal is observed at Q beyond P_1 and P_2. The axis SQ in perpendicular to the plane containing P_1 and P_2.

(i) Sketch the diagram that represents the experimental layout. [2]

(ii) Give the expression for the time average of an electric field. [2]

(iii) By considering the total electric field at Q, show that the light intensity I at Q is given by:

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\,\mathrm{Re}[\gamma_{12}(\tau)]$$

where $\gamma_{12}(\tau)$ is the complex degree of partial coherence and τ is the time difference for propagation along the paths SP_1Q and SP_2Q. I_1 and I_2 are the intensities observed at Q along the separate paths SP_1Q and SP_2Q respectively. [8]

(iv) Explain how $\gamma_{12}(\tau)$ can be measured experimentally, and determine the fringe visibility when $I_1 = I_2$. [8]

3. Explain what is meant by a Virtual State? [2]

Derive expressions for the two-photon ionization rate of an atom as a function of laser intensity I when the intermediate state is (a) Real and (b) Virtual. [4]

Helium can be two-photon ionized by resonant radiation at 58.4 nm and also by non-resonant radiation at 40.0 nm. Determine the resonant and non-resonant ionization rates in terms of I^2. In both cases, take the excitation cross-section to be 10^{-12} m^2 and the ionization cross-section to be 10^{-14} m^2. Also, assume a typical lifetime of 6 ns. [4]

A parity-forbidden transition $|0\rangle \rightarrow |1\rangle$ occurs at an energy $2h\nu$, where ν is the frequency of the incident photon. Explain how by using an intermediate Virtual State, Doppler-free spectroscopy is achieved. [4]

Describe an experiment to measure the hyperfine separations in the $3\,^2S_{1/2} \rightarrow 5\,^2S_{1/2}$ two-photon transition in sodium. The nuclear spin of sodium is 3/2. [6]

4. What conditions must apply in order that the two states $|1\rangle$ and $|2\rangle$ are excited in a coherent superposition of states? [2]

Distinguish between *excitation* coherence and *perturbative* coherence. [2]

Consider a 3-level atom in which excitation produces a coherent superposition of states. Write down the wave function for this superposition of states, and derive a formula that shows the existence of interference. [5]

A 475 keV He^+ beam undergoes charge exchange in a foil, producing a coherent superposition of the states $He(3\ ^3P_1)$ and $(3\ ^3P_2)$ which are separated by 658 MHz. How many quantum beat oscillations can be observed in the interference pattern over a distance of 1 cm? [3]

Briefly describe a beam foil apparatus in which quantum beat oscillations may be measured by excitation coherence. [4]

In hydrogen, the $2\ ^2S_{1/2}$ and $2\ ^2P_{1/2}$ levels are separated by the Lamb Shift (1057 MHz) and have lifetimes of 163 years and 16 ns respectively. Is it possible to measure a quantum beat oscillation arising from these two levels? If so, how can it be done? [4]

5. State the selection rules for the absorption and emission of *plane* and *circular* polarized light. [2]

Consider the $5\ ^2S_{1/2} \rightarrow 5\ ^2P_{1/2}$ transition in Rb which has Clebsch-Gordan coefficients of $\sqrt{2}$ and 1 for $|\Delta m_J| = 1$ and $\Delta m_J = 0$ transitions respectively. Explain how the atoms become orientated using circularly polarized light. [3]

In the $5\ ^2S_{1/2} \rightarrow 5\ ^2P_{3/2}$ transition in Rb, 8/9 of the atoms are in the $5\ ^2S_{+1/2}$ level after two pumping cycles. Determine the ratio of the Clebsch-Gordan coefficients for the active transitions when pumping with light of the appropriate circular polarization. Assume all population is initially in the $5\ ^2S_{-1/2}$ level. [4]

Derive an expression for the velocity change Δv of an atom after a one-photon recoil, and determine Δv for Na (23 a.m.u.) using the $3^2S_{1/2} \rightarrow 3^1P_{1/2}$ transition ($\tau = 16$ ns) at ~ 600 nm. [2]

In a chirped laser beam, how many recoils are necessary to slow Na from 500 m/s to 20 m/s? [2]

Estimate the cooling length required in this case. [2]

Describe the operation of a Zeeman Trap. [5]

END OF PAPER