UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

M.Sci.

Physics 4421: Atom and Photon Physics

COURSE CODE	:	**PHYS4421**
UNIT VALUE	:	**0.50**
DATE	:	**03-MAY-06**
TIME	:	**14.30**
TIME ALLOWED	:	**2 Hours 30 Minutes**

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

Unified atomic mass unit: $u = 1.66 \times 10$^-27 kg

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

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

1. Draw an energy level diagram of helium showing the transitions:

   (i) Electric Dipole

   (ii) Spin Forbidden

   (iii) Autoionizing.

   In each case, give a typical lifetime. [3]

   Describe, making use of schematic diagrams, a coincidence method by which the lifetime of the resonance transition in helium can be measured. [6]

   Explain what is meant by a virtual state. [2]

   The $2\ ^1S$ level at 20.6 eV in helium can decay by two photon emission to the $1\ ^1S$ ground state.

   (i) Estimate the lifetime of the virtual state. [3]

   (ii) What effect can the $2\ ^3S$ level at 19.8 eV have on the two photon decay? [3]

   Assuming the $1\ ^1S \rightarrow n\ ^1P$ excitation sequence to be hydrogenic, determine the lifetime of the $n = 100$ Rydberg level if the lifetime of $10\ ^1P$ is 6 μs. [3]

2. Show how two counter-propagating laser beams can remove the Doppler bandwidth. [3]

Describe a two photon absorption experiment in which the hyperfine levels in the $3\ ^2S \rightarrow 5\ ^2S$ level in sodium can be observed. The nuclear spin of sodium is 3/2. [7]

Derive an expression for the non-resonant two-photon transition rate in terms of excitation cross section, lifetime of the virtual state and the laser intensity. [6]

In sodium, the $3\ ^2S \rightarrow 5\ ^2S$ transition at 301.1 nm is probed using two photon absorption spectroscopy. The laser wavelength is 602.2 nm, and the laser intensity is 10 W m^{-2}. Noting that the $3\ ^2S \rightarrow 3\ ^2P$ transition occurs at 589 nm, determine the two photon transition rate. Neglect hyperfine structure and take the value 10^{-20} m^2 for the excitation cross section. [4]

3. Define the coherence time, τ_0, of a light source with frequency ν. [2]

Determine the coherence length of a light source of wavelength 800 nm and bandwidth 30 nm. [2]

Given that the degree of coherence, $\gamma(\tau)$, of a point light source is:

$$\gamma(\tau) = \left(1 - \frac{\tau}{\tau_0}\right) \exp(i\omega\tau),$$

where $\omega = 2\pi c / \lambda$. Show that the natural coherence arising from two incoherent points 'a' and 'b' of an extended light source in a Young's slits geometry is given by

$$\frac{1}{2}\left(1 - \frac{\tau_a}{\tau_0}\right)\left(1 - \frac{\tau_b}{\tau_0}\right)[1 + \cos\omega(\tau_b - \tau_a)],$$

where τ_a and τ_b are the respective time differences of the paths from the point sources 'a' and 'b' through the slits. [8]

Determine an expression for the transverse coherence. [4]

Estimate the distance, at ground level, over which reflected sunlight from a jumbo jet (size ~40m) at a height of 10^4 m is coherent. [4]

4. In Sisyphus cooling, two counter-propagating linearly polarized laser beams, along the z-axes, with orthogonal polarization create a standing wave with a z-dependent polarization.

(i) Derive expressions showing how this polarization changes with z. [6]

(ii) Using the effect of light shifts on the $5\ ^2S \rightarrow 5\ ^2P$ transition in rubidium, explain how the atom is cooled. [8]

A rubidium atom (mass 85 u) cooled to 0.1 K has its residual velocity along the z direction. An electron beam of 50 eV incident along the x direction excites the $5\ ^2S \rightarrow 5\ ^2P$ transition at 780 nm. Determine the resultant motion of the rubidium atom when the electron is:
(i) backscattered along the x direction
(ii) scattered along the z direction. [6]

5. Explain the origin of the Lamb Dip in an inhomogeneously broadened laser transition. [3]

Give an expression showing the relationship of atomic velocity to the detuning of the laser and transition frequencies. [3]

Describe the method of Hansch to measure the Lamb Shift of the $n = 2$ levels in atomic hydrogen. Show clearly with an energy level diagram the transitions involved. [6]

State the different decay routes for the $2\ ^2S_{1/2} \rightarrow 1\ ^2S_{1/2}$ transition in hydrogen. Which route is least probable? [4]

What would be the net effect on the lifetime of the $2\ ^2S_1$ level if the Lamb Shift was:

(i) zero?

(ii) 5 GHz? [4]