Answer 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.

$m_p = 1.67 \times 10^{-27}$ kg

$e = 1.60 \times 10^{-19}$ C

$h = 6.63 \times 10^{-34}$ Js

[Part marks]

1. Using helium as an example draw an energy level diagram and indicate

(i) an Electric Dipole Transition
(ii) a Magnetic Dipole Transition
(iii) an Auto Ionizing Transition

and in each case give typical lifetime values. [3]

In hydrogen the $2^2S_{½}$ level has two single photon decay routes - name them.
What role do virtual states play in two photon decay of $2^2S_{½}$?
Estimate the most probable lifetime of the virtual state. [6]

Describe a method for measuring the lifetime of a metastable atomic state using a pulsed electron beam. [4]

In Simultaneous Electron Photon Excitation (SEPE) an electron and photon combine to excite a stationary state.

(1) Draw the Feynman Diagrams for all possible first order processes and explain the associated excitation processes. [4]
(2) Describe in detail an experiment in which the SEPE of the $He(2^3S_1)$ can be measured. [3]

2. Why is a Population Inversion necessary for laser operation? [2]
Describe the operation of a YAG laser. [5]
Describe the operation of a DYE laser. [5]
Sketch the optical arrangement employed in a Transversely Pumped dye laser. [2]

Explain the Principle of Saturation Absorbtion Spectroscopy. [2]

Using a dye laser tunable between the n = 2 and n = 3 manifold in hydrogen describe how the 2s-Lamb Shift in hydrogen can be measured. [4]

3. Two interacting light beams with space time co-ordinates (r_1t_1) and (r_2t_2) and electric fields E have a correlation function

$$\langle E^*(r_1t_1)\, E\,(r_2t_2)\rangle = \frac{2\bar{I}}{\varepsilon_0 c} \exp\,(iw_0\tau - \gamma|\tau|)$$

(i) Define all the terms in the correlation function. [4]
(ii) Give the general expressions for the first order coherence, g_{12}. [1]
(iii) Derive g_{12} for a chaotic light field with finite bandwidth. [4]
(iv) Neglecting geometric effects what other factor will influence the fringe visibility in a Young experiment? [2]
(v) In a Young's slit experiment estimate the coherence length associated with a Doppler broadened light source. [1]
(vi) In what way does the interference in a Young experiment differ from that in a Hanbury-Brown-Twiss experiment? [2]
(vii) Explain the Hanbury-Brown-Twiss experiment and show how the second order correlation function is obtained. [6]

4. What conditions must apply in order that two states $|1\rangle$ and $|2\rangle$ are coherently excited? [2]

Distinguish between EXCITATION coherence and PERTURBATIVE coherence. [2]

Consider a 3-level atom in which excitation produces a superposition of states. Write down the wave function for this superposition of states and derive a formula which shows the existence of QUANTUM BEATS. [6]

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

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

How must the apparatus be modified in order to observe Lyman α beats in hydrogen by perturbative coherence? How does the beat pattern depend on the strength of the perturbation? [3]

5. What is meant by OPTICAL PUMPING? [2]

Consider the $5^2S_{½}$ - $5^2P_{½}$ transition in Rb which has Clebsch-Gordan coefficients of $\sqrt{2}$ and 1 for $|\Delta m| = 1$ and $\Delta m_J = 0$ transitions respectively. Explain how the atoms become orientated using σ_+ light. [3]

Describe an apparatus which could be used to detect the presence of orientation in Rb. [3]

Derive an expression for the velocity change, Δv, of an atom after a one photon recoil and determine Δv for Na (23 amu) using the $3^2S_{½}$ - $3^1P_{½}$ transition (τ = 16 ns) at ~600nm. [2]

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

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

Describe how atoms are held in a Zeeman Trap. [6]

END OF PAPER