EXAM with Answers:

Course title: "Atomic Spectroscopy of Collisional and Radiative Processes in Astrophysical Plasmas"

with Workshop on: SUPERSTRUCTURE, R-Matrix codes

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Total points = 52
Note: Number of points for each question is given within parentheses
Good luck!

1. i) What are the most abundant elements in the universe? (1)
- H, He, Li, ..., Fe
ii) How do elements heavier than iron formed (1)?
- During supernoval explosions, also through the s-process of neutrino capture
iii) How do we describe the distribution of electrons in plasma? (1)
- Using Maxwellian distribution function
2. i) How do we describe a black body? (1)
- By Planck distribution function
ii) Why do we see the yellow sun? (1)
- Planck function peaks at yellow wavelength at solar surface temperature
iii) What is opacity? (1)
- It is a quantity that measures the radiation transfer in the medium
iv) What are the main atomic processes in astrophysical plasmas? (2)
- Photo-excitation, Photoionization, Electron-ion recombination, Electron-impact ionization, electron impact ionization
3. i) Which part of an atom is studied under Atomic Physics? (1)
- Electronic properties
ii) How do we identify an element from an astrophysical spectra? (1)
- By matching the observed spectral lines to those at the same energy positions of various known elements
iii) How do we detect a black hole? (1)
- By studying the surrounding matter
(iv) What happends to photons trying to escape black hole gravity? (1)
- Give out part of their energies

4. i) Write down the Rydberg formula for hydrogen? (1)

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$$\mathcal{E}_{\mathbf{n'}} = \mathcal{R}_{\mathrm{H}} \frac{\mathbf{1}}{\mathbf{n^2}}$$

ii) What is the K_α line? (1)

- Absorption or emission line for 1s-2p transition

iii) Give its wavelength of Lymanα. (1)

- 1215 $\mathring{A}$

5. i) What is quantum defect? (1)

- It is the effect of electron screening around nucleus of a multi-electron system

ii) Write down the Rydberg formula with the quantum defect. (1)

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$$\mathbf{E(nl)} = \frac{\mathbf{z^2}}{\mathbf{(n-\mu)^2}}$$

iii) When is this formula used? (1)

- Largely for energies of excited levels

6. i) What is configuration for an atomic system? (1)

- Arrangement of electrons in the atom or ion

ii) Write down the ground configuration of oxygen atom with 8 elecrons. (1)

- Oxygen: $1s^2 2s^2 2p^4$ **iii) What quantum numbers do we use to write the symmetry of an electronic state with quantum numbers? (1)**

- $^{(2S+1)}L_J^\pi$ **7. i) What are equivalent and non-equivalent states? (1)**

- Equivalent: More than one electron in the outer orbital

Non-equivalent: One electron in the outer electron

ii) Which kind has less number of LS states and why? (2)

- Equivalent electron states are less due to Pauli exclusion principle of no two electrons can have the same state

iii) Write down all the LS states of configuration 2p3d and list them in energy according to Hund's rule. (3)

- $2p3d \rightarrow\ ^3(F,D,P)^o,\ ^1(F,D,P)^o$

iv) Write down all the LS states of configuration $2p^2$ and list them in energy order following Hund's rule. (2)- $^3P,^1D,^1S$

8. i) Why do we get exact wavefunction for hydrogen, but not for multi-electron systems? (1)

- Hydrogen has one electron with central potention to the nuclues and hence can be solved exactly for the wave function

ii) What equations do we need to solve for muti-electron systems: 1) non-relativistic, 2) relatvistic approximations? (3)

- 1) Hartree-Fock equations, 2) Dirac-Fock equations or Breit-Pauli equations

9. i) What approximations can we use to include relativistic effects for higher accuracy? (1)

- Direc equation

ii) What interaction splits the LS term energy in to fine structure levels? (1)

- Spin-orbit interaction term

10. i) Wtat are the types of radiatve transition we have studied (2) and what is the name of the rules that regulate the transitions (1)?

- Electrci dipole, quadrupole, octupole, and magnetic dipole, quadrupole

ii) What does SUPERSTRUCTURE calculate (2)?

- Wave functions, energies of the atomic system, and transition parameters - A, f, S

Give an eample of an allowed transition (1)

- $^3P \rightarrow^3 (S, P, D)^0$

iii) How can the lifetime of an atomic state be calculated? (1)

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$$\tau_k(s) = \frac{1}{\sum_i A_{ki}(s^{-1})}$$

11. i) What is an autoionizing state? (1)

- A doubly excited state above the ionization threshold

ii) What does it lead to? (1) How does it appear in a process (1)

- Autoionization or dielectronic recombination

12. i) What is the difference in features between hydrogenic and multi-electron photoionization? (1)

- Multi-electron systems have resonances, hydrogen does not

ii) Which approximation can calculate the resonances naturally? (1)

- Close coupling approximation

14. i) What is the relation between photoionization and electron-ion recombination? (1)

- They are inverse proceses and connected by Principle of Detailed balance

ii) How many ways does electron-ion recombination take place? (1)

- Two ways: Radiative recombination, dielectronic recombination

iii) Which is the method that incorporates them together? (1)

- Unified method

15. What do R-matrix codes calculate? (1) What atomic process did you studied using R-matrix codes and quantity did you calculate? (2)

- Quantities for atomic processes. Electron impact excitation, Collision strength