

**EXAM:**

Course title: "Atomic Astrophysics with computational Workshops"

Cairo University, Cairo, Egypt, Apr 5 - Apr 21, 2018

- By Sultana N. Nahar, The Ohio State University, USA

Total points = 52

Note: Number of points for each question is given within parentheses

Good luck!

1. i) How do we study astronomical objects? (1)
- ii) What are the most abundant elements in the universe? (1)
- iii) How do elements heavier than iron form (1)?
2. i) How do we describe the distribution of electrons in plasma? (1)
- ii) How do we describe radiation field distribution of a black body? (1)
- iii) Why do we see the sun yellow? (1)
- iv) What is opacity? (1)
3. i) Which part of an atom is studied under Atomic Physics? (1)
- ii) How do we identify an element from an astrophysical spectra? (1)
- ii) What are the main atomic processes in astrophysical plasmas? (2.5)
4. i) Write down the Rydberg formula for hydrogen energies? (1)
- ii) What is the  $K_\alpha$  line? (1)
- iii) Give its wavelength of Lyman $\alpha$  line. (1)
5. i) What is quantum defect? (1)
- ii) Write down the Rydberg formula with the quantum defect. (1)
6. i) What is configuration for an atomic system? (1)
- ii) Write down the ground configuration of oxygen atom with 8 electrons. (1)
- iii) What are the quantum numbers to describe the symmetry of an electronic state? Write them in the form of a quantum state. (1)
7. i) What are equivalent and non-equivalent states? (1)
- ii) Which kind has less number of LS states and why? (2)
- iii) Write down all the LS states of configuration  $1s3d$  and list them in energy according to Hund's rule. (3)
8. i) Why do we get exact wavefunction for hydrogen, but not for multi-electrons systems? (1)
- ii) What approximations, in 1) non-relativistic and in 2) relativistic approach, do we use to solve for multi-electron systems? (3)
9. i) What types of radiative transition have we studied (2) and what is the name of the rules that regulate the transitions (1)?

- ii) What does SUPERSTRUCTURE calculate (2)?
  - iii) How can the lifetime of an atomic state be calculated? (1)
10. i) What is an autoionizing state? (1)
- ii) How does it appear in a process (1)
11. i) What is the relation between photoionization and electron-ion recombination? (1) What principle gives the relation between the two? (1)
12. i) How many ways does electron-ion recombination take place? (1)
- ii) Which is the method that incorporates them together? (1)

**EXAM with Answers:**

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1. i) How do we study astronomical objects? (1)  
 - By studying the radiation or signal that reach us.
- ii) What are the most abundant elements in the universe? (1)  
 - H, He, Li, ..., Fe
- iii) How do elements heavier than iron formed (2)?  
 - During supernoval explosions, also through the s-process of neutrino capture. The recent finding is formation during mergers of black holes, neutron stars
2. i) How do we describe the distribution of electrons in plasma? (1)  
 - Using Maxwellian distribution function
- ii) How do we describe radiation field distribution of a black body? (1)  
 - By Planck distribution function
- iii) Why do we see the sun yellow? (1)  
 - Planck function peaks at yellow wavelength at solar surface temperature
- iv) What is opacity? (1)  
 - It is a quantity that measures the radiation absorption in the medium
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) What are the main atomic processes in astrophysical plasmas? (2.5)  
 - Photo-excitation, Photoionization, Electron-ion recombination, Electron-impact ionization, electron impact ionization
4. i) Write down the Rydberg formula for hydrogen energies? (1)  
 -

$$\mathcal{E}_{n'} = \mathcal{R}_H \frac{1}{n^2}$$

ii) What is the  $K_\alpha$  line? (1)

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

iii) Give the wavelength of Lyman $\alpha$  line. (1)

- 1215 Å

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)

-

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

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 electrons. (1)

- Oxygen:  $1s^2 2s^2 2p^4$

iii) What are the quantum numbers to describe the symmetry of an electronic state? Write them in the form of a quantum state. (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 orbital

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 1s3d and list them in energy according to Hund's rule. (3)

-  $1s3d \rightarrow {}^3D, {}^1D$

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

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

ii) What approximations, in 1) non-relativistic and in 2) relativistic approach, do we use to solve for multi-electron systems? (3)

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

9. i) What types of radiative transition have we studied (2) and what is the name of the rules that regulate the transitions (1)?

- Electric dipole, quadrupole, octupole, and magnetic dipole, quadrupole. The selection rules govern the transition criteria

ii) What does SUPERSTRUCTURE calculate (2)?

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

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

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

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

- A doubly excited state above the ionization threshold

ii) How does it appear in a process (1)

- It introduces a resonance

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

- They are inverse processes.

What principle gives the relation between the two? (1)

They are connected by the Principle of Detailed balance

12. i) 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