# EXAM:

**Course title: "Atomic Astrophysics with coomputational Workshops**
**University of Rajshahi, Rajshahi, Bangladesh, October 30-31, 2017**
**- 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) What are the most abundant elements in the universe? (1)**
**ii) How do elements heavier than iron form (1)?**
**iii) How do we describe the distribution of electrons in plasma (1)?**

**2. i) How do we describe the radiation of a black body? (1)**
**ii) Why do we see the yellow sun? (1)**
**iii) What is opacity? (1)**
**iv) What are the main atomic processes in astrophysical plasmas? (2)**

**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)**

**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$\alpha$. (1)**

**5. i) What is quantum defect? (1)**
**ii) Write down the Rydberg formula with the quantum defect. (1)**
**iii) When is this formula used? (1)**

**6. i) What is configuration for an atomic system? (1)**
**ii) Write down the ground configuration of oxygen atom with 8 elecrons. (1)**
**iii) What quantum numbers do we use to write the symmetry of an electronic state with quantum numbers? (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 2p3d and list them in energy according to Hund's rule. (3)**
**iv) Write down all the LS states of configuration $2p^2$ and list them in energy order following Hund's rule. (2)**

**8. i) Why do we get exact wavefunction for hydrogen, but not for multi-electrons systems? (1)**
**ii) What are the equations we need to solve for muti-electron systems: 1) non-relativistic, 2) relatvistic approximations? (2)**
**9. i) What approximations can we use to include relativistic effects for higher accuracy? (1)**
**ii) What interaction splits the LS term energy in to fine structure levels? (1)**

**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)?**
**ii) What does SUPERSTRUCTURE calculate (2)?**
**iii) Give an eample of an allowed transition (1)**
**iv) How can the lifetime of an atomic state be calculated? (1)**

**11. i) What is an autoionizing state? (1)**
**ii) What does it lead to? (1) How does it appear in a process (1)**

**12. i) What is the difference in features between hydrogenic and multi-electron photoionization? (1)**
**ii) Which approximation can calculate the resonances naturally? (1)**

**14. i) What is the relation between photoionization and electron-ion recombination? (1)**
**ii) How many ways does electron-ion recombination take place? (1)**
**iii) Which is the method that incorporates them together? (1)**

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

## EXAM with Answers:

**Course title: "Atomic astrophysics with computational workshops"**
**University of Rajshahi, Rajshahi, Bangladesh, Oct 30-31, 2017**
**- 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) 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 radiation field of 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**

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

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

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

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

**iii) Give its wavelength of Lyman$\alpha$. (1)**

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**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)**

-

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

**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)**

**-**

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

**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**