EXAM with Answers:

Course title: "Astrophysical Atomic Processes, Opacity, & Cancer Treatment with X-rays" & Computational workshops with R-matrix Codes & SUPERSTRUCTURE
Cairo University, Giza, Egypt, Oct 21 - Nov 11, 2016
- By Sultana N. Nahar, The Ohio State University, USA
Under the MOA between Ohio State University & Cairo University
Total points = 51 (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 the elements heavier than iron form? (1)
- During supernova explosions, also through the s-process of neutrino capture in the stars
2. i) In what state most of the matter exists in the universe? (1)
- In plasma state
ii) How do we describe the distribution of electrons in plasma? (1)
- Using Maxwellian distribution function
3. i) How do we describe the radiation from a black body? (1)
- By Planck distribution function
ii) What is the temperature on the surface of the sun and why do we see the yellow sun? (2)
- Solar surface temperature is 5770 K
- Planck function peaks at yellow wavelength on solar surface temperature or mostly yellow photons reach us
4. What is opacity? (1)
- It is a quantity that measures the radiation absorption in the medium
5. What are the main atomic processes in astrophysical plasmas? (2.5)
- i) Photo-excitation, ii) Photoionization, iii) Electron-ion recombination, iv) Electron-impact ionization, v) electron impact ionization
6. i) Which properties 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 spectrum of surrounding matter

iv) What happens to photons trying to escape black hole gravity? (1)
- Give out part of their energies
7. i) Write down the Rydberg formula for hydrogen lines? (1)
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$$\mathcal{E}_{\mathbf{n'}} = \mathcal{R}_{\mathrm{H}} \left[\frac{\mathbf{1}}{\mathbf{n^2}} - \frac{\mathbf{1}}{\mathbf{n'^2}} \right]$$

ii) What is the K_α line? (1)
- Absorption or emission line for 1s-2p transition
iii) What is the wavelength of Lymanα line? (1)
- 1215 $\mathring{A}$
8. i) What is quantum defect? (1)
- It is the effect due to 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
9. i) What is configuration for an atomic system? (1)
- Arrangement of electrons in the atom or ion
ii) Write down the 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)
- $^{(2S+1)}L_J^{\pi}$
10. 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)
- $^3P, ^1D, ^1S$
11. 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. Multi-electron system becomes complicated by angular dependence
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
iii) What approximations can we use to include relativistic effects for higher accuracy? (1)
- Dirac-Fock equation
12. i) Wtat are the types of radiatve transition we have studied? (2)
- Electric dipole, electric quadrupole, electric octupole, and magnetic dipole, magnetic quadrupole
ii) What is the name of the rules that regulate the transitions? (1)
- Selection rules
ii) What does SUPERSTRUCTURE calculate? (2)
- Wave functions, energies of the atomic system, and transition parameters - A, f, S
iii) Give an eample of an allowed transition (1)
- $^3\mathrm{P} \rightarrow ^3 (\mathrm{S}, \mathrm{P}, \mathrm{D})^0$
iv) How can the lifetime of an atomic state be calculated? (1)
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$$\tau_{\mathrm{k}}(\mathrm{s}) = \frac{1}{\sum_{\mathrm{i}} \mathrm{A_{ki}}(\mathrm{s}^{-1})}$$

13. i) What is an autoionizing state? (1)
- A doubly excited state above the ionization threshold
ii) How does it appear in a process? (0.5)
- As a resonance
14. 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
15. 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
16. i) What do the R-matrix codes calculate? (1)
- Quantities for atomic processes.
ii) What atomic process did you study using R-matrix codes and what quantity did you calculate? (2)
Electron impact excitation, Collision strength