BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF SCIENCE EDUCATION

SCIENCE AND MATHEMATICS EDUCATION DEPARTMENT

MPH505: ATOMIC AND OPTICAL PHYSICS

SEMESTER EXAMINATIONS AUG 2023

DURATION: THREE HOURS

INSTRUCTIONS

*Answer **ALL** parts of Section A and any **THREE** questions from Section B. Section A carries 40 marks and Section B carries 60 marks.*

You may need:

$m_e = 9.11 \times 10^{-31} kg$, $c = 3.00 \times 10^{8} m/s$, $\varepsilon_0 = 8.85 \times 10^{-12} F/m$, $h = 6.63 \times 10^{-34} Js$

SECTION A

*(Answer **all** questions)*

1 **(a)** State the *two* atomic energy units. Give the relationship between these two atomic energy units. [3]

(b) Define *screening*. Describe the shell model of multi-electron atoms. [6]

(c) Draw a diagram to illustrate X-ray emission spectra for tungsten at two different electron voltages. Describe how the continuous spectrum and the line spectrum are produced. [7]

(d) In Dirac theory, which two states of hydrogen in the n = 2 manifold are degenerate? Discuss which of the following effects lifts the degeneracy, and why? The Lamb shift, Darwin term, the size of the proton, the mass of the proton, spin orbit coupling. [6]

(e) Compare and contrast the Thompson model and the Rutherford model of the atom. What are the weaknesses of both models? [7]

(f) By considering the case where the atom is enclosed within a cavity containing black body radiation at temperature, T show that,

$$A_{21} = \frac{8\pi n^3 h\upsilon^3}{c^3} B_{21}$$

when $g_1 B_{12} = g_2 B_{21}$

where g_1 and g_2 are the degeneracies of the two levels respectively. [11]

[Spectral energy density of black body radiation is given by

$u(\nu) = \frac{8\pi n^3 h\nu^3}{c^3} \frac{1}{\exp\left(\frac{h\nu}{k_B T}\right)-1}$]

SECTION B

*(Answer any **three** questions)*

2 **(a)** State the postulates of Bohr's theory. Deduce an expression for the energy of the *n*th orbit of hydrogen atom. [12]

(b) Calculate for hydrogen atom the velocity of an electron in ground state and the radius of Bohr orbit in the ground state. [8]

3 **(a)** Describe the *three* types of interactions that occur inside an atom. State the rough energy scales for these different interactions. Draw a diagram to illustrate the hierarchy of spectral lines from these interactions. [12]

(b) Sodium has an atomic number of 11.

Calculate its radii and energies of the principal atomic shells. [Bohr radius of hydrogen, $a_H = 5.29 \times 10^{-10}$m, Rydberg constant, $R_H = 13.6$eV] [8]

4 Consider an atom which consists of a lithium nucleus (Z = 3) and (instead of an electron) a muon μ with a mass $m_\mu/m_e = 207$.

(a) Derive (using any model) the expression for the Bohr radius for the hydrogen atom. [5]

(b) For the muonic atom above, what is Bohr radius and the binding energy of the 1s state, relative to the hydrogen atom. [4]

(c) Compare atoms with same nuclear charge, but with an electron or a muon in the 1s state. What is the ratio of the relativistic corrections to the binding? [4]

(d) Consider a lithium nucleus (Z = 3) with three electrons. In units of the Rydberg constant, what is its ground state? What is the ground state energy, if one of the electrons is replaced by a negative muon? Neglect all interactions between electrons and muons. [7]

6 **(a)** **(i)** Write out all of the allowed combinations of the angular momentum quantum number, the magnetic quantum number and the spin quantum number for n=2. [5]

(ii) In an atom there are two quantum states for each combination of l and m_l because of the electron spin. Find the total number of electron states for $n = 4$ and $n = 2$. [5]

(b) Nitrogen has 7 electrons and maximum L of 3. Find values of spin, s; orbital quantum numbers, L; and all states of nitrogen in the form $^{2s+1}L_j$. [10]

END OF EXAMINATION