

Calculation of the Resonance Energies, Quantum Defect and Effective Nuclear Charge of Highly Excited Rydberg Series in the Photoionization Spectra of Se II and Rb II Ions Using the Modified Atomic Orbital Theory

Abdou Faye¹, Malick Sow^{1,2}, Moustapha Kebe¹, Papa Mamadou Ndiaye¹, Oumar Baba Dia¹, Cheikh Ndiaye¹, Cheikh Tidjane Diouf¹, Astou Ngom¹, Oumar Absatou Niasse^{1,2}

¹Department of Physics, Faculty of Sciences and Technologies, University Cheikh Anta Diop of Dakar, Dakar, Senegal

²Institute of Applied Nuclear Technology, University Cheikh Anta Diop of Dakar, Dakar, Senegal

Email: abdou55.faye@ucad.edu.sn

How to cite this paper: Faye, A., Sow, M., Kebe, M., Ndiaye, P.M., Dia, O.B., Ndiaye, C., Diouf, C.T., Ngom, A. and Niasse, O.A. (2026) Calculation of the Resonance Energies, Quantum Defect and Effective Nuclear Charge of Highly Excited Rydberg Series in the Photoionization Spectra of Se II and Rb II Ions Using the Modified Atomic Orbital Theory. *Journal of Applied Mathematics and Physics*, **14**, 2273-2297.

<https://doi.org/10.4236/jamp.2026.146111>

Received: April 30, 2026

Accepted: June 19, 2026

Published: June 22, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

In this paper, we reported the energy positions, quantum defect and effective nuclear charge of the $4s^2 4p^2 ({}^3P_2)nd$, $4s^2 4p^2 ({}^1D_2)ns$, $4s^2 4p^2 ({}^2D_2)ns ({}^2D_2)$, $4s^2 4p^2 ({}^1D_2)nd ({}^2P_{1/2}^o)$ and $4s^2 4p^2 ({}^2D_2)ns ({}^2S)$ Rydberg series of Se⁺ ions and $4s^2 4p^2 ({}^2P_{1/2}^o)nd ({}^1P_1^o)$ Rydberg series of Rb⁺. Calculations are performed using the semi-empirical Modified Atomic Orbital theory (MAOT) from $n = 55$. Very good agreements are seen between the present calculations and the available theoretical and experimental data. The present predicted data up to $n = 55$ may be of great importance to the atomic physics community, particularly in understanding the chemical evolution of Selenium in the Universe. Furthermore, the accurate data presented in this work may serve as a valuable guideline for future experimental investigations and alternative theoretical studies.

Keywords

Rydberg Series, Resonance Energy, Quantum Defect, Photoionization, Effective Charge and Modified Atomic Orbital Theory

1. Introduction

The study of photoionization for atoms and ions is a fundamental process that

allows to understand the chemical evolution of the universe elements. Thus, photoionization is very important in many fields of astrophysics, especially stars, astrophysical plasmas, fusion with inertial confinement. Almost half of the neutron capture elements (atomic number $Z > 30$ atomic number) in the universe, are created by slow nucleosynthesis [1]-[5]. Both theoretical models and experimental data have explored the photoionization of Se^+ , Se^{2+} , Se^{3+} , Se^{4+} , and Se^{5+} ions to shed light on selenium's chemical development in space. Synchrotron Radiation (SR) provided the experimental means to determine absolute cross-sections for single photoionization. These experiments produced precise resonance energies and quantum defects related to various Rydberg series identified in the spectra of Se^+ , Se^{3+} and Se^{5+} [6] and Se^{2+} [7]. From the theoretical point of view, studies have been carried out to compare with the measurements of simple photoionization section made by previous experiments. Indeed, the Breit-Pauli and Dirac-Coulomb matrix approximations was used by McLaughlin *et al.* [8] to calculate the first theoretical resonance energies and quantum defects for the Rydberg dominant series of the Se^+ ion. Sakho *et al.* [9] completed predictions on the resonance energies that belong to numerous Rydberg series of the Se^{2+} and Se^{5+} ions using Screening Constant by Unit Nuclear Charge (SCUNC) method. In the same way, Sakho [10] calculated high resonance energies belonging to many Rydberg series of Se^{3+} and Rb^+ using the SCUNC formalism. In the same way, Sakho calculated high resonance energies belonging to many Rydberg series of Se^+ using the SCUNC formalism [11]. The data derived from Rubidium photoionization serves as a critical resource for simulating astrophysical processes, specifically the nucleosynthesis of heavy elements [12]. In this work, we intend to provide precise data on the photoionization of Se^+ and Rb^+ ions that may be useful guideline for the physical atomic community. In addition, we aim to demonstrate the possibilities of using the semi-empirical procedure of MAOT [13]-[16] to reproduce experimental data with high precision. Thus, we calculated the resonance energies and quantum defect for the $4s^2 4p^2 ({}^3P_2)nd$, $4s^2 4p^2 ({}^1D_2)ns$, $4s^2 4p^2 ({}^2D_2)ns ({}^2D_2)$, $4s^2 4p^2 ({}^1D_2)nd ({}^2P_{1/2}^o)$ and $4s^2 4p^2 ({}^2D_2)ns ({}^2S)$ Rydberg series originating from the $4s^2 4p^3 \left({}^2P_{1\frac{3}{2}}^o \right)$ and $4s^2 4p^3 \left({}^2D_{3\frac{5}{2}}^o \right)$ states of Se^+ and $4s^2 4p^2 ({}^2P_{1/2}^o)nd ({}^1P_1^o)$ Rydberg series of Rb^+ converging to the $(3d^{10} 4s^2 4p^5 2P_{3/2})$ serie limits in Rb^{2+} . Section 2 presents the theoretical procedure adopted in this work with a brief description of the MAOT formalism [13]-[16] and the analytical expressions used in the calculations. In Section 3, we present and discuss our current findings, comparing them with existing data from the literature (experimental and theoretical data). In Section 4, we present a conclusion and summary of this study.

2. Theory

2.1. Brief Description of the MOAT Formalism

In the framework of the Modified Atomic Orbital Theory (MAOT), total energy

of a $(\nu\ell)$ -given orbital is expressed in the form [13]-[15]

$$E = -\frac{[Z - \sigma(\ell)]^2}{\nu^2} \quad (1)$$

For an atomic system of several electrons M , the total energy is given by (in Rydberg):

$$E = -\sum_{i=1}^M \frac{[Z - \sigma_i(\ell)]^2}{\nu_i^2} \quad (2)$$

With respect to the usual spectroscopic notation $(N\ell, n\ell')^{2S+1}L^\pi$, this equation becomes

$$E = -\sum_{i=1}^M \frac{[Z - \sigma_i(^{2S+1}L^\pi)]^2}{\nu_i^2}. \quad (3)$$

In the photoionization of atoms and ions, energy resonances are generally measured relatively to the E_∞ converging limit of a given $(^{2S+1}L_J)nl$ -Rydberg serie. For these states, the general expression of the energy resonance E_n is given

$$E_n = E_\infty - \frac{1}{n^2} \left\{ Z - \sigma_1(^{2S+1}L_J) - \sigma_2(^{2S+1}L_J) \times \frac{1}{n} - \sigma_2^\alpha(^{2S+1}L_J) \right. \\ \left. \times (n-m) \times (n-q) \sum_k \frac{1}{f_k(n, m, q, s)} \right\}^2 \quad (4)$$

In this equation, m and q ($m < p$) denote the principal quantum numbers of the $(^{2S+1}L_J)nl$ -Rydberg serie of the considered atomic system used in the empirical determination of the $\sigma_i(^{2S+1}L_J)$ -screening constants s represents the spin of the nl -electron ($s = 1/2$), E_∞ is the energy value of the serie limit generally determined from NIST atomic database, E_n denote correspond energy resonance and Z represents the nuclear charge of the considered element. The only problem that one lay face by using the MAOT formalism is linked to the determination of the $\sum_k \frac{1}{f_k(n, m, q, s)}$ -term. The correct expression of this term is determined iteratively by imposing general Equation (4) to give accurate data with a constant quantum defect or decreasing throughout the serie considered. The value of α is generally fixed to 1 and or 2 during the iteration. The standard quantum defect expansion is given as follows:

$$E_n = E_\infty - \frac{RZ_{core}^2}{(n - \delta)^2} \quad (5)$$

In the equation, R , E_∞ , Z_{core} and δ are the Rydberg constant, the converging limit, the electric charge of the core ion and the quantum defect, respectively.

Z_{core} is directly obtained by the photoionization process from an atomic X^{p+} system:

$$X^{p+} + h\nu \rightarrow X^{(p+1)+} + e^-. \text{ We find then } Z_{core} = p + 1. \quad (6)$$

From Equation (5) we obtain the expression for the quantum defect δ :

$$\delta = n - Z_{core} \times \sqrt{\frac{R}{E_{\infty} - E_n}} \quad (7)$$

2.2. Resonances Energy of the Transitions States of S_e^+ Ions

In the framework of the Modified Atomic Orbital Theory (MOAT) formalism the energy position of the $4s^2 4p^2 ({}^3P_2)nd$, $4s^2 4p^2 ({}^1D_2)ns$,

$4s^2 4p^2 ({}^2D_2)ns ({}^2D_2)$, $4s^2 4p^2 ({}^1D_2)nd ({}^2P_{1/2}^o)$ and $4s^2 4p^2 ({}^2D_2)ns ({}^2S)$

Rydberg series originating from the $4s^2 4p^3 ({}^2P_{1,3}^o)$ and $4s^2 4p^3 ({}^2D_{3,5}^o)$ states

of Se^+ and $4s^2 4p^2 ({}^2P_{1/2}^o)nd ({}^1P_1^o)$ Rydberg series of Rb^+ converging to the

$(3d^{10} 4s^2 4p^5 2P_{3/2})$ serie limits in Rb^{2+} . Using the general Equation (4), we obtain

the expressions of the resonant energies of the Rydberg series of the Se^+ ions orig-

inating from the $4s^2 4p^3 ({}^2P_{1,3}^o)$ and $4s^2 4p^3 ({}^2D_{3,5}^o)$ and of the Rydberg se-

ries of the Rb^+ series.

➤ **For the $4s^2 4p^3 ({}^2D_{3/2}^o) \rightarrow 4s^2 4p^2 ({}^3P_2)nd$ transition**

$$E_n = E_{\infty} - \frac{1}{n^2} \left\{ Z - \sigma_1 - \frac{\sigma_2}{n} - \sigma_2^2 (n-m)(n-q) \left[\frac{1}{(n+m+q+s)^5} + \frac{1}{(n-m+q+4s)^6} + \frac{1}{(n+m-q+s)^7} \right] \right\}^2 \quad (8)$$

Using the experimental data of the Advanced Light Sources (ALS) measure-

ments of Esteves *et al.* [5], we obtain for the state $4s^2 4p^2 ({}^3P_2)11d$ and

$4s^2 4p^2 ({}^3P_2)12d$ respectively $E_{11} = 19.595$ eV ($m = 11$) and $E_{12} = 19.668$ eV (q

$= 12$). Energy limit is given by ALS data, we find $E_{\infty} = 20.049$ eV. Using these data,

We then get using Equation (8): $\sigma_1 = 32.005995$ and $\sigma_2 = -0.169044$.

➤ **For the $4s^2 4p^3 ({}^2D_{5/2}^o) \rightarrow 4s^2 4p^2 ({}^3P_2)nd$ transition**

$$E_n = E_{\infty} - \frac{1}{n^2} \left\{ Z - \sigma_1 - \frac{\sigma_2}{n} - \sigma_2^2 (n-m)(n-q) \left[\frac{1}{(n+4m+q-2s)^2 (n+q+m-2s)} + \frac{1}{(n+m-q+s)^4} + \frac{1}{(n+m-q+s)^5} \right] \right\}^2 \quad (9)$$

The screening constants in (9) are determined from the transition energies measured by Esteves *et al.* [5]. Using the experimental data of the Advanced Ligh

Sources (ALS) measured by Esteves, we obtain $E_{11} = 19.523$ eV and $E_{12} = 19.595$

eV respectively for $4s^2 4p^3 ({}^2D_{5/2}^o) \rightarrow 4s^2 4p^2 ({}^3P_2)11d$ and

$4s^2 4p^3 ({}^2D_{5/2}^o) \rightarrow 4s^2 4p^2 ({}^3P_2)12d$. From ALS, we find $E_{\infty} = 19.973$ eV. Thus,

Equation (9) gives us: $\sigma_1 = 32.003467$ and $\sigma_2 = -0.043651$.

➤ **For the** $4s^2 4p^3 \left({}^2 D_{3/2}^o \right) \rightarrow 4s^2 4p^2 \left({}^2 D_2 \right) ns \left({}^2 D_2 \right)$ **transition**

$$E_n = E_\infty - \frac{1}{n^2} \left\{ Z - \sigma_1 - \frac{\sigma_2}{n} - \sigma_2^2 (n-m)(n-q) \left[\frac{1}{(n+7q+m+s)^3} + \frac{1}{(n+6m-2q-s)^4} + \frac{1}{(n+m-q-s)^5} + \frac{1}{(n+m-q-2s)^6} \right] \right\}^2 \quad (10)$$

For the $4s^2 4p^3 \left({}^2 D_{3/2}^o \right) \rightarrow 4s^2 4p^2 \left({}^2 D_2 \right) 11s \left({}^2 D_2 \right)$ and

$4s^2 4p^3 \left({}^2 D_{3/2}^o \right) \rightarrow 4s^2 4p^2 \left({}^2 D_2 \right) 12s \left({}^2 D_2 \right)$ levels the experimental data of the

Advanced Light Sources by Esteves *et al.* [5] are $E_{11} = 19.890$ eV ($m = 11$) and $E_{12} = 20.214$ eV ($q = 12$) in eV. ALS [5] gives us the limit energy, $E_\infty = 21.176$ eV. In that case, we find using Equation (10) $\sigma_1 = 32.046604$ and $\sigma_2 = -1.390788$.

➤ **For the** $4s^2 4p^3 \left({}^2 P_{1/2} \right) \rightarrow 4s^2 4p^2 \left({}^1 D_2 \right) ns$ **transition**

$$E_n = E_\infty - \frac{1}{n^2} \left\{ Z - \sigma_1 - \frac{\sigma_2}{n} - \sigma_2^2 (n-m)(n-q) \left[\frac{1}{(n-2s)^2 (n+q+m+s)^2} + \frac{1}{(n-m+q+6s)^4} + \frac{1}{(n+2m-q+9s)^5} \right] \right\}^2 \quad (11)$$

Using the experimental data of the Advanced Light Sources (ALS) measurements of Esteves *et al.* [5], we obtain for the state

$4s^2 4p^3 \left({}^2 P_{1/2} \right) \rightarrow 4s^2 4p^2 \left({}^1 D_2 \right) 7s$ and $4s^2 4p^3 \left({}^2 P_{1/2} \right) \rightarrow 4s^2 4p^2 \left({}^1 D_2 \right) 8s$ respectively $E_7 = 18.667$ eV ($m = 7$) and $E_8 = 18.991$ eV ($q = 8$). Energy limit is given by ALS data, we find, $E_\infty = 19.955$ eV. Using these data, We then get using Equation (11): $\sigma_1 = 32.040633$ and $\sigma_2 = -1.360699$.

➤ **For the** $4s^2 4p^3 \left({}^2 P_{3/2} \right) \rightarrow 4s^2 4p^2 \left({}^1 D_2 \right) ns$ **transition**

$$E_n = E_\infty - \frac{1}{n^2} \left\{ Z - \sigma_1 - \frac{\sigma_2}{n} - \sigma_2^2 (n-m)(n-q) \left[\frac{1}{(n-q+m+6s)^3} + \frac{1}{(n+m-q+4s)^4} + \frac{1}{(n+m-q+2s)^5} \right] \right\}^2 \quad (12)$$

From Advanced Light Source (ALS) [5], we obtain for the

$4s^2 4p^3 \left({}^2 P_{3/2} \right) \rightarrow 4s^2 4p^2 \left({}^1 D_2 \right) 7s$ and $4s^2 4p^3 \left({}^2 P_{3/2} \right) \rightarrow 4s^2 4p^2 \left({}^1 D_2 \right) 8s$, $E_7 = 18.560$ eV ($m = 7$) and $E_8 = 18.886$ eV ($q = 8$). We find, $E_\infty = 19.853$ eV. We find then using Equation (12), we obtain $\sigma_1 = 32.04338$ and $\sigma_2 = -1.409165$.

➤ **For the** $4s^2 4p^3 \left({}^2 P_{1/2}^o \right) \rightarrow 4s^2 4p^2 \left({}^1 D_2 \right) nd \left({}^2 P_{1/2}^o \right)$ **transition**

$$E_n = E_\infty - \frac{1}{n^2} \left\{ Z - \sigma_1 - \frac{\sigma_2}{n} - \sigma_2^2 \times (n-m) \times (n-q) \left[\frac{1}{(n+4q+m+2s)^3} + \frac{1}{(n+4m-q+6s)^4} + \frac{1}{(n+m+3q-s)^5} \right] \right\}^2 \quad (13)$$

Using the experimental data of the Advanced Light Source measurements of Esteves *et al.* [5], we obtain for the state $4s^2 4p^3 ({}^2P_{1/2}^o) \rightarrow 4s^2 4p^2 ({}^1D_2) 6d ({}^2P_{1/2}^o)$ and $4s^2 4p^3 ({}^2P_{1/2}^o) \rightarrow 4s^2 4p^2 ({}^1D_2) 7nd ({}^2P_{1/2}^o)$ respectively $E_6 = 18.351$ eV ($m = 6$) and $E_7 = 18.790$ eV ($q = 7$). Energy limit is given by ALS [5] data, we find $E_\infty = 19.955$ eV. Using these data, We then get using Equation (13): $\sigma_1 = 32.022401$ and $\sigma_2 = -0.495149$.

➤ **For the $4s^2 4p^3 ({}^2P_{1/2}^o) \rightarrow 4s^2 4p^2 ({}^2D_2) ns ({}^2S)$ transition**

$$E_n = E_\infty - \frac{1}{n^2} \left\{ Z - \sigma_1 - \frac{\sigma_2}{n} - \sigma_2^2 (n-m)(n-q) \left[\frac{1}{(n+m+q-s)^5} + \frac{1}{(n+m-q-s)^6} \right] \right\}^2 \quad (14)$$

For the $4s^2 4p^3 ({}^2P_{1/2}^o) \rightarrow 4s^2 4p^2 ({}^2D_2) 6s ({}^2S)$ and $4s^2 4p^3 ({}^2P_{1/2}^o) \rightarrow 4s^2 4p^2 ({}^2D_2) 7s ({}^2S)$ levels the experimental data of the Advanced Light Sources by Esteves *et al.* [5] are $E_6 = 18.393$ eV ($m = 6$) and $E_7 = 18.816$ eV ($q = 7$) in eV. ALS [5] gives us the limit energy, $E_\infty = 19.955$ eV. In that case, we find using Equation (14) $\sigma_1 = 32.020399$ and $\sigma_2 = -0.320232$.

➤ **For the $4s^2 4p^2 ({}^2P_{1/2}^o) nd ({}^1P_1^o) \rightarrow 3d^{10} 4s^2 4p^5 ({}^2P_{1/2}^o)$ transition,**

$$E_n = E_\infty - \frac{1}{n^2} \left\{ Z - \sigma_1 - \frac{\sigma_2}{n} - \sigma_2^2 (n-m)(n-q) \left[\frac{1}{(n+m+q-s)^5} + \frac{1}{(n+m-q-s)^6} \right] \right\}^2 \quad (15)$$

For the $4s^2 4p^2 ({}^2P_{1/2}^o) 8d ({}^1P_1^o)$ and $4s^2 4p^2 ({}^2P_{1/2}^o) 9d ({}^1P_1^o)$ levels the experimental data of the synchrotron radiation (SR) and dual laser plasma (DPL) [17] are $E_8 = 27.39$ ($m = 8$) and $E_9 = 27.50$ ($q = 9$) in eV. SR-DPL [17] gives us the limit energy, $E_\infty = 28.204$ eV. In that case, we find using Equation (15) $\sigma_1 = 35.071807$ and $\sigma_2 = -1.071424$.

3. Resultants and Discussions

The calculated resonance energies (in eV) for the Se⁺ Rydberg series are presented in **Tables 1-7**. These results, obtained via the MOAT formalism, are compared with SCUNC calculations (Sakho *et al.* 2022) and ALS experimental data from Esteves *et al.* [5] for the Se II ion. Similarly, our results for the Rb⁺ Rydberg series

are summarized in **Table 8** and **Table 9**. These are compared with theoretical data from Sakho *et al.* using the SCUNC method, Hartree-Fock calculations with exchange and relativistic corrections (HXR), and Dirac R-matrix results from McLaughlin and Babb. Comparisons are also made with Synchrotron Radiation (SR) and Dual Laser Plasma (DLP) experimental data, which, to our knowledge, represent the only available benchmarks. For all series studied, the MOAT resonance energies demonstrate high stability, enabling calculations up to $n = 55$ including both quantum defects and effective charge.

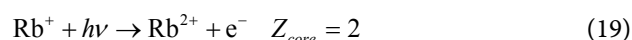
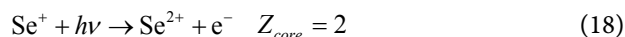
Theoretical and measured energy positions can be analyzed by calculating the Z effective charge in relationship with the quantum defect (δ). The relationship between Z^* and δ is in the form:

$$Z^* = \frac{Z_{core}}{\left(1 - \frac{\delta}{n}\right)} \quad (16)$$

According to this equation, each Rydberg series must satisfy the following conditions:

$$\begin{cases} Z^* \geq Z_{core} & \text{if } \delta \geq 0 \\ Z^* \geq Z_{core} & \text{if } \delta < 0 \\ \lim_{n \rightarrow \infty} Z^* = Z_{core} \end{cases} \quad (17)$$

For the photoionisation of the Se^+ and Rb^+ ion considered in this work Equation (6) give.



In **Table 1** we present the MAOT resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge (Z^*) of the $4s^2 4p^2 ({}^3P_2) nd$ Rydberg series converging to the (3P_2) serie limits in Se^{2+} threshold origin $\text{Se}^+ 4s^2 4p^3 ({}^2P_{3/2}^o)$ metastable state. Results presented in this table are calculated via Equation (8). The quantum defect and effective nuclear charge Z^* agree well with the MAOT analysis condition of Equation (17). We also note that the quantum defect decreases as the principal quantum number increases. For $n = 11$ up to $n = 25$ Our results are compared with of the experimental data of ALS [5] and those of Sakho (2022) [11] obtained theoretically. The comparison shows very good agreement. The absolute deviations $|\Delta E|$ between MOAT and ALS are small (on the order of 0.0001 eV). For $n = 26$ up to 40, our results are one only compared with SCUNC theoretical calculation of Sakho and comparison is considered very satisfactory. Thus, our value of 20.015 eV for $n = 40$ is in good agreement with Sakho's calculated result of 20.015 eV. This allows us to expect the present results on the resonance energies for this Rydberg series up to $n = 55$ to be accurate.

We present in **Table 2** resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge (Z^*) of the $4s^2 4p^2 ({}^3P_2) nd$ Rydberg series converging to the (3P_2) serie limits in Se^{2+} threshold origin $\text{Se}^+ 4s^2 4p^3 ({}^2P_{5/2}^o)$ metastable state.

Table 1. Resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge Z^* of the $4s^2 4p^2(^3P_2)nd$ Rydberg series converging to the $(^3P_2)$ serie limits in Se^{2+} threshold origin $Se^+ 4s^2 4p^3(^2P_{3/2}^o)$ metastable state. The present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [11] and the ALS experimental measurements Esteves *et al.* [5]. $|\Delta E|$ denotes the energy difference between the MAOT calculations and the ALS measurement. The results are expression in electron-volt (eV). (1 Ryd = 0.5 au = 13.605698 eV).

$4s^2 4p^3(^2P_{3/2}^o) \rightarrow 4s^2 4p^2(^3P_2)nd$										
n	MAOT			ALS			SCUNC			ΔE
	E	δ	Z^*	E	δ	Z^*	E	δ	Z^*	
11	19.595	0.0513	2.0094	19.595	0.051	2.0093	19.595	0.051	2.0094	0.0000
12	19.668	0.0484	2.0081	19.668	0.051	2.0085	19.668	0.052	2.0087	0.0000
13	19.7247	0.0454	2.0070	19.724	0.051	2.0079	19.724	0.052	2.0080	0.0007
14	19.7696	0.0424	2.0061	19.769	0.035	2.0073	19.770	0.052	2.0073	0.0004
15	19.8060	0.0395	2.0053	19.805	0.020	2.0068	19.807	0.052	2.0069	0.0010
16	19.8354	0.0365	2.0046	19.835	0.051	2.0064	19.835	0.052	2.0064	0.0004
17	19.8599	0.0335	2.0039	19.860	0.051	2.0060	19.860	0.052	2.0060	0.0001
18	19.8805	0.0305	2.0034	19.880	0.051	2.0057	19.880	0.051	2.0057	0.0005
19	19.8978	0.0275	2.0029	19.897	0.051	2.0054	19.897	0.051	2.0054	0.0008
20	19.9126	0.0245	2.0025	19.912	0.051	2.0051	19.912	0.051	2.0051	0.0006
21	19.9253	0.0216	2.0021	19.925	0.051	2.0049	19.925	0.051	2.0048	0.0003
22	19.9364	0.0186	2.0017	19.936	0.051	2.0046	19.936	0.051	2.0046	0.0004
23	19.946	0.0156	2.0014	19.946	0.051	2.0044	19.946	0.051	2.0044	0.0000
24	19.9544	0.0126	2.0010	19.954	0.051	2.0042	19.954	0.051	2.0042	0.0004
25	19.9619	0.0096	2.0008	19.962	0.051	2.0011	19.962	0.051	2.0042	0.0001
26	19.9685	0.0066	2.0005				19.968	0.051	2.0029	
27	19.9743	0.0036	2.0003				19.974	0.051	2.0037	
28	19.9796	0.0006	2.0000				19.979	0.051	2.0036	
29	19.9843	-0.0024	1.9998				19.984	0.051	2.0033	
30	19.9886	-0.0054	1.9996				19.988	0.051	2.0032	
31	19.9924	-0.0084	1.9995				19.992	0.051	2.0031	
32	19.9959	-0.0114	1.9993				19.996	0.051	2.0030	
33	19.9991	-0.0144	1.9991				19.999	0.051	2.0029	
34	20.002	-0.0174	1.9990				20.002	0.051	2.0028	
35	20.0046	-0.0204	1.9988				20.004	0.051	2.0028	
36	20.0071	-0.0234	1.9987				20.007	0.051	2.0027	
37	20.0093	-0.0264	1.9986				20.009	0.051	2.0026	
38	20.0114	-0.0294	1.9985				20.011	0.051	2.0025	
39	20.0133	-0.0324	1.9983				20.013	0.051	2.0025	
40	20.015	-0.0354	1.9982				20.015	0.051	2.0025	
41	20.0167	-0.0384	1.9981							
42	20.0182	-0.0414	1.9980							
43	20.0196	-0.0444	1.9979							

Continued

44	20.0209	-0.0474	1.9978		
45	20.0222	-0.0504	1.9978		
46	20.0233	-0.0534	1.9977		
47	20.0244	-0.0564	1.9976		
48	20.0254	-0.0594	1.9975		
49	20.0264	-0.0624	1.9975		
50	20.0273	-0.0654	1.9974		
51	20.0281	-0.0684	1.9973		
52	20.0289	-0.0714	1.9973		
53	20.0297	-0.0745	1.9972		
54	20.0304	-0.0775	1.9971		
55	20.0281	-0.0805	1.9971		
∞	20.0490			20.0490	20.0490

Table 2. Resonance Energy (E_n , eV), quantum defect (δ) and effective nuclear charge Z^* of the $4s^2 4p^2(^3P_2)nd$ Rydberg series converging to the $(^3P_2)$ serie limits in Se^{2+} threshold origin $Se^+ 4s^2 4p^3(^2D^o_{5/2})$ metastable state. The present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [11] and the ALS experimental measurements Esteves *et al.* [5]. $|\Delta E|$ denotes the energy difference between the MAOT calculations and the ALS measurement. The resultats are expression in electron-volt (eV). (1 Ryd = 0.5 au = 13.605698 eV).

n	MAOT			ALS			SCUNC			ΔE
	E	δ	Z^*	E	δ	Z^*	E	δ	Z^*	
11	19.523	0.0028	2.0005	19.523	0.003	2.0005	19.523	0.003	2.0005	0.000
12	19.595	0.001	2.0002	19.595	0.003	2.0005	19.595	0.003	2.0005	0.000
13	19.651	-0.0007	1.9999	19.651	0.003	2.0005	19.651	0.003	2.0004	0.000
14	19.6954	-0.0024	1.9997	19.697	-0.040	1.9943	19.695	0.003	2.0004	0.001
15	19.7313	-0.0041	1.9995	19.733	-0.050	1.9933	19.731	0.003	2.0004	0.001
16	19.7606	-0.0057	1.9993	19.764	-0.110	1.9863	19.760	0.003	2.0003	0.003
17	19.7849	-0.0074	1.9991	19.789	-0.200	1.9767	19.785	0.003	2.0003	0.004
18	19.8052	-0.0091	1.999	19.811	-0.350	1.9618	19.805	0.003	2.0003	0.005
19	19.8224	-0.0108	1.9989	19.827	-0.320	1.9669	19.822	0.003	2.0003	0.004
20	19.8371	-0.0125	1.9988	19.842	-0.300	1.9704	19.837	0.003	2.0003	0.005
21	19.8498	-0.0142	1.9986	19.855	-0.400	1.9626	19.850	0.003	2.0003	0.005
22	19.8607	-0.0159	1.9986	19.855	-0.400	1.9643	19.861	0.003	2.0002	0.005
23	19.8703	-0.0176	1.9985	19.865	-0.450	1.9616	19.870	0.003	2.0002	0.005
24	19.8787	-0.0192	1.9984				19.878	0.003	2.0002	
25	19.8861	-0.0209	1.9983				19.886	0.003	2.0002	
26	19.8926	-0.0226	1.9983				19.892	0.003	2.0002	
27	19.8985	-0.0243	1.9982				19.898	0.003	2.0002	
28	19.9037	-0.026	1.9981				19.904	0.003	2.0002	

Continued

29	19.9084	-0.0277	1.9981	19.908	0.003	2.0002
30	19.9126	-0.0293	1.998	19.913	0.003	2.0002
31	19.9165	-0.031	1.998	19.916	0.003	2.0002
32	19.9200	-0.0327	1.998	19.920	0.003	2.0002
33	19.9231	-0.0344	1.9979	19.923	0.003	2.0002
34	19.926	-0.036	1.9979	19.926	0.003	2.0002
35	19.9287	-0.0377	1.9978	19.929	0.003	2.0002
36	19.9311	-0.0394	1.9978	19.931	0.003	2.0001
37	19.9333	-0.041	1.9978	19.933	0.003	2.0001
38	19.9354	-0.0427	1.9978	19.935	0.003	2.0001
39	19.9373	-0.0444	1.9977	19.937	0.003	2.0001
40	19.9391	-0.046	1.9977	19.939	0.003	2.0001
41	19.9407	-0.0477	1.9977			
42	19.9422	-0.0494	1.9977			
43	19.9436	-0.051	1.9976			
44	19.945	-0.0527	1.9976			
45	19.9462	-0.0544	1.9976			
46	19.9473	-0.056	1.9976			
47	19.9484	-0.0577	1.9975			
48	19.9494	-0.0594	1.9975			
49	19.9504	-0.061	1.9975			
50	19.9513	-0.0627	1.9975			
51	19.9521	-0.0643	1.9975			
52	19.9529	-0.066	1.9975			
53	19.9537	-0.0677	1.9975			
54	19.9544	-0.0693	1.9974			
55	19.9551	-0.071	1.9974			
∞	19.9730		19.973	19.973		

Table 3. Resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge Z^* of the $4s^2 4p^2(^2D_2)ns(^2D_2)$ Rydberg series converging to the $(^2D_2)$ serie limits in Se^{2+} threshold origin $Se^+ 4s^2 4p^3(^2P_{3/2}^o)$ metastable state. The present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [11] and the ALS experimental measurements Esteves *et al.* [5]. $|\Delta E|$ denotes the energy difference between the MAOT calculations and the ALS measurement. The resultats are expression in electron-volt (eV). (1 Ryd = 0.5 au = 13.605698 eV).

n	MAOT			ALS			SCUNC			ΔE
	E	δ	Z^*	E	δ	Z^*	E	δ	Z^*	
7	19.89	0.495	2.1521	19.890	0.495	2.1522	19.890	0.496	2.1525	0.000
8	20.214	0.479	2.1272	20.214	0.480	2.1276	20.211	0.487	2.1303	0.000
9	20.4298	0.46	2.1077	20.428	0.470	2.1102	20.425	0.485	2.1143	0.001

Continued

10	20.5805	0.44	2.0921	20.576	0.480	2.1008	20.575	0.484	2.1019	0.004
11	20.6898	0.42	2.0794	20.685	0.470	2.0893	20.684	0.483	2.0920	0.004
12	20.7716	0.399	2.0688	20.770	0.420	2.0725	20.766	0.482	2.0838	0.001
13	20.8344	0.378	2.0599	20.830	0.460	2.0734	20.829	0.481	2.0770	0.004
14	20.8836	0.356	2.0522	20.883	0.380	2.0558	20.878	0.481	2.0712	0.000
15	20.923	0.334	2.0456	20.922	0.360	2.0492	20.918	0.481	2.0663	0.001
16	20.9549	0.312	2.0398	20.955	0.300	2.0382	20.950	0.481	2.0620	0.000
17	20.9811	0.289	2.0346	20.985	0.100	2.0118	20.977	0.481	2.0582	0.004
18	21.0029	0.266	2.03	21.008	0	2.0000	20.999	0.481	2.0549	0.005
19	21.0213	0.243	2.0259	21.025	0	2.0000	21.017	0.481	2.0519	0.004
20	21.0369	0.22	2.0222	21.040	0	2.0000	21.033	0.481	2.0492	0.003
21	21.0503	0.196	2.0188	21.053	0	2.0000	21.047	0.481	2.0469	0.002
22	21.0618	0.172	2.0158	21.063	0	2.0000	21.058	0.481	2.0447	0.001
23	21.0718	0.148	2.013	21.073	0	2.0000	21.069	0.481	2.0427	0.001
24	21.0805	0.124	2.0104				21.078	0.481	2.0409	
25	21.0882	0.1	2.008				21.085	0.481	2.0393	
26	21.095	0.075	2.0058				21.092	0.481	2.0377	
27	21.1011	0.05	2.0037				21.099	0.482	2.0363	
28	21.1065	0.026	2.0018				21.104	0.482	2.0350	
29	21.1113	0.001	2.0001				21.109	0.482	2.0338	
30	21.1156	-0.024	1.9984				21.114	0.482	2.0327	
31	21.1195	-0.049	1.9968				21.118	0.483	2.0316	
32	21.1231	-0.074	1.9954				21.121	0.483	2.0306	
33	21.1263	-0.099	1.994				21.125	0.483	2.0297	
34	21.1293	-0.125	1.9927				21.128	0.484	2.0289	
35	21.132	-0.15	1.9915				21.130	0.484	2.0280	
36	21.1344	-0.176	1.9903				21.133	0.484	2.0273	
37	21.1367	-0.201	1.9892				21.135	0.484	2.0265	
38	21.1388	-0.227	1.9881				21.137	0.485	2.0258	
39	21.1407	-0.252	1.9871				21.139	0.485	2.0252	
40	21.1425	-0.278	1.9862				21.141	0.485	2.0246	
41	21.1441	-0.304	1.9853							
42	21.1456	-0.33	1.9844							
43	21.147	-0.356	1.9836							
44	21.1484	-0.382	1.9828							
45	21.1496	-0.408	1.982							
46	21.1508	-0.434	1.9813							
47	21.1518	-0.46	1.9806							
48	21.1529	-0.486	1.98							
49	21.1538	-0.512	1.9793							

Continued

50	21.1547	-0.538	1.9787		
51	21.1555	-0.564	1.9781		
52	21.1563	-0.591	1.9775		
53	21.1571	-0.617	1.977		
54	21.1578	-0.643	1.9765		
55	21.1584	-0.67	1.9759		
∞	21.1760			21.176	21.176

Table 4. Resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge Z^* of the $4s^2 4p^2 ({}^1D_2) ns$ Rydberg series converging to the $({}^1D_2)$ serie limits in Se^{2+} threshold origin $Se^+ 4s^2 4p^3 ({}^2P_{1/2}^o)$ metastable state. The present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [11] and the ALS experimental measurements Esteves *et al.* [5]. $|\Delta E|$ denotes the energy difference between the MAOT calculations and the ALS measurement. The resultats are expression in electron-volt (eV). (1 Ryd = 0.5 au = 13.605698 eV).

n	MAOT			ALS			SCUNC			ΔE
	E	δ	Z^*	E	δ	Z^*	E	δ	Z^*	
7	18.667	0.4997	2.1538	18.667	0.500	2.1538	18.667	0.500	2.1538	0.0000
8	18.991	0.4863	2.1295	18.991	0.488	2.1294	18.988	0.496	2.1323	0.0000
9	19.2067	0.4721	2.1107	19.207	0.470	2.1102	19.203	0.494	2.1162	0.0003
10	19.3574	0.4571	2.0958	19.357	0.460	2.0964	19.353	0.492	2.1036	0.0004
11	19.4668	0.4415	2.0836	19.467	0.440	2.0833	19.462	0.491	2.0935	0.0003
12	19.5488	0.4252	2.0735	19.549	0.420	2.0725	19.544	0.490	2.0852	0.0002
13	19.6117	0.4085	2.0649	19.613	0.380	2.0602	19.607	0.489	2.0782	0.0013
14	19.6611	0.3912	2.0575	19.663	0.355	2.0520	19.657	0.489	2.0724	0.0019
15	19.7006	0.3736	2.0511	19.702	0.340	2.0464	19.697	0.488	2.0673	0.0014
16	19.7326	0.3557	2.0455				19.729	0.488	2.0629	
17	19.759	0.3374	2.0405				19.755	0.488	2.0591	
18	19.7809	0.3189	2.0361				19.778	0.488	2.0557	
19	19.7994	0.3001	2.0321				19.796	0.488	2.0527	
20	19.815	0.2812	2.0285				19.812	0.488	2.0500	
21	19.8285	0.262	2.0253				19.826	0.488	2.0476	
22	19.84	0.2427	2.0223				19.837	0.488	2.0454	
23	19.8501	0.2233	2.0196				19.848	0.488	2.0434	
24	19.8589	0.2037	2.0171				19.857	0.488	2.0415	
25	19.8666	0.184	2.0148				19.864	0.488	2.0398	
26	19.8735	0.1643	2.0127				19.871	0.489	2.0383	
27	19.8795	0.1444	2.0108				19.878	0.489	2.0369	
28	19.885	0.1245	2.0089				19.883	0.489	2.0355	
29	19.8898	0.1044	2.0072				19.888	0.489	2.0343	
30	19.8942	0.0844	2.0056				19.893	0.489	2.0332	

Continued

31	19.8981	0.0642	2.0042		19.897	0.490	2.0321
32	19.9017	0.0441	2.0028		19.900	0.490	2.0311
33	19.905	0.0238	2.0014		19.904	0.490	2.0302
34	19.9079	0.0036	2.0002		19.907	0.491	2.0293
35	19.9106	-0.0168	1.999		19.909	0.491	2.0284
36	19.9131	-0.0371	1.9979		19.912	0.491	2.0277
37	19.9154	-0.0575	1.9969		19.914	0.491	2.0269
38	19.9175	-0.0779	1.9959		19.916	0.492	2.0262
39	19.9194	-0.0983	1.995		19.918	0.492	2.0256
40	19.9212	-0.1188	1.9941		19.920	0.492	2.0249
41	19.9228	-0.1392	1.9932				
42	19.9244	-0.1597	1.9924				
43	19.9258	-0.1803	1.9917				
44	19.9271	-0.2008	1.9909				
45	19.9284	-0.2213	1.9902				
46	19.9295	-0.2419	1.9895				
47	19.9306	-0.2625	1.9889				
48	19.9317	-0.2831	1.9883				
49	19.9326	-0.3037	1.9877				
50	19.9335	-0.3243	1.9871				
51	19.9344	-0.3449	1.9866				
52	19.9352	-0.3655	1.986				
53	19.9359	-0.3862	1.9855				
54	19.9366	-0.4068	1.985				
55	19.9373	-0.4275	1.9846				
...							
∞	19.955			19.955		19.955	

Table 5. Resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge Z^* of the $4s^2 4p^2(^1D_2)ns$ Rydberg series converging to the (1D_2) serie limits in Se^{2+} threshold origin $Se^+ 4s^2 4p^3(^2P_{3/2}^o)$ metastable state. The present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [11] and the ALS experimental measurements Esteves *et al.* [5]. $|\Delta E|$ denotes the energy difference between the MAOT calculations and the ALS measurement. The resultats are expression in electron-volt (eV). (1 Ryd = 0.5 au = 13.605698 eV).

$4s^2 4p^3(^2P_{3/2}) \rightarrow 4s^2 4p^2(^1D_2)ns$										
n	MAOT			ALS			SCUNC			ΔE
	E	δ	Z^*	E	δ	Z^*	E	δ	Z^*	
7	18.5600	0.5123	2.1579	18.560	0.512	2.1578	18.560	0.512	2.1578	0.000
8	18.8860	0.498	2.1328	18.886	0.500	2.1333	18.883	0.509	2.1358	0.000
9	19.101	0.4919	2.1156	19.102	0.490	2.1152	19.099	0.506	2.1192	0.001
10	19.251	0.4902	2.1031	19.250	0.500	2.1052	19.249	0.504	2.1062	0.001
11	19.360	0.4905	2.0933	19.359	0.500	2.0952	19.359	0.503	2.0959	0.001

Continued

12	19.442	0.4915	2.0854	19.442	0.500	2.0870	19.441	0.502	2.0873	0.000
13	19.505	0.4925	2.0788	19.505	0.500	2.0800	19.505	0.501	2.0802	0.000
14	19.555	0.493	2.073	19.554	0.500	2.0741	19.554	0.501	2.0742	0.001
15	19.594	0.4928	2.0679	19.594	0.500	2.0690	19.594	0.500	2.0690	0.000
16	19.627	0.4916	2.0634	19.627	0.500	2.0652	19.626	0.500	2.0645	0.000
17	19.6534	0.4895	2.0593	19.653	0.500	2.0610	19.653	0.500	2.0606	0.000
18	19.676	0.4865	2.0556	19.675	0.500	2.0571	19.675	0.500	2.0571	0.001
19	19.6943	0.4825	2.0521	19.694	0.500	2.0541	19.694	0.500	2.0540	0.001
20	19.7102	0.4775	2.0489				19.710	0.500	2.0513	
21	19.7239	0.4717	2.046				19.724	0.500	2.0488	
22	19.7356	0.4651	2.0432				19.735	0.500	2.0465	
23	19.7459	0.4577	2.0406				19.745	0.500	2.0444	
24	19.7549	0.4495	2.0382				19.754	0.500	2.0426	
25	19.7628	0.4406	2.0359				19.762	0.500	2.0408	
26	19.7698	0.4311	2.0337				19.769	0.500	2.0393	
27	19.776	0.421	2.0317				19.775	0.501	2.0378	
28	19.7815	0.4102	2.0297				19.781	0.501	2.0364	
29	19.7865	0.399	2.0279				19.786	0.501	2.0352	
30	19.7909	0.3872	2.0262				19.790	0.501	2.0340	
31	19.795	0.375	2.0245				19.794	0.502	2.0329	
32	19.7986	0.3623	2.0229				19.798	0.502	2.0319	
33	19.802	0.3493	2.0214				19.801	0.502	2.0309	
34	19.805	0.3358	2.0199				19.804	0.502	2.0300	
35	19.8077	0.322	2.0186				19.807	0.503	2.0291	
36	19.8103	0.3078	2.0172				19.810	0.503	2.0283	
37	19.8126	0.2933	2.016				19.812	0.503	2.0276	
38	19.8148	0.2784	2.0148				19.814	0.504	2.0269	
39	19.8167	0.2633	2.0136				19.816	0.504	2.0262	
40	19.8186	0.248	2.0125				19.818	0.504	2.0255	
41	19.8203	0.2323	2.0114							
42	19.8218	0.2164	2.0104							
43	19.8233	0.2003	2.0094							
44	19.8247	0.184	2.0084							
45	19.8259	0.1675	2.0075							
46	19.8271	0.1507	2.0066							
47	19.8282	0.1338	2.0057							
48	19.8293	0.1167	2.0049							
49	19.8302	0.0995	2.0041							
50	19.8312	0.082	2.0033							
51	19.832	0.0645	2.0025							

Continued

52	19.8328	0.0467	2.0018		
53	19.8336	0.0289	2.0011		
54	19.8343	0.0109	2.0004		
55	19.835	-0.0072	1.9997		
∞	19.8530			19.853	19.853

Table 6. Resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge Z^* of the $4s^2 4p^2(^1D_2)nd(^2P_{1/2}^o)$ Rydberg series converging to the (1D_2) serie limits in Se^{2+} threshold origin Se^+ $4s^2 4p^3(^2P_{1/2}^o)$ metastable state. The present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [11] and the ALS experimental measurements Esteves *et al.* [5]. $|\Delta E|$ denotes the energy difference between the MAOT calculations and the ALS measurement. The results are expression in electron-volt (eV). (1 Ryd = 0.5 au = 13.605698 eV).

n	MAOT			ALS			SCUNC			$ \Delta E $
	E	δ	Z^*	E	δ	Z^*	E	δ	Z^*	
6	18.351	0.1751	2.0601	18.351	0.175	2.0600	18.351	0.175	2.0602	0.000
7	18.790	0.1652	2.0483	18.790	0.165	2.0483	18.785	0.179	2.0524	0.000
8	19.071	0.155	2.0395	19.071	0.152	2.0395	19.066	0.176	2.0451	0.000
9	19.261	0.1446	2.0327	19.262	0.140	2.0316	19.256	0.174	2.0394	0.001
10	19.396	0.1341	2.0272	19.395	0.140	2.0284	19.392	0.172	2.0350	0.001
11	19.495	0.1236	2.0227	19.494	0.130	2.0239	19.491	0.171	2.0315	0.001
12	19.570	0.113	2.019	19.571	0.100	2.0168	19.566	0.169	2.0286	0.001
13	19.628	0.1025	2.0159	19.633	0	2.000	19.624	0.168	2.0263	0.005
14	19.674	0.092	2.0132	19.683	-0.150	1.9788	19.671	0.168	2.0242	0.008
15	19.710	0.0814	2.0109	19.718	-0.150	1.9802	19.708	0.167	2.0225	0.007
16	19.740	0.071	2.0089				19.738	0.166	2.0210	
17	19.765	0.0605	2.0071				19.763	0.166	2.0197	
18	19.786	0.0501	2.0056				19.784	0.165	2.0186	
19	19.8036	0.0397	2.0042				19.802	0.165	2.0175	
20	19.8185	0.0293	2.0029				19.817	0.165	2.0166	
21	19.8314	0.019	2.0018				19.830	0.165	2.0158	
22	19.8425	0.0086	2.0008				19.841	0.164	2.0151	
23	19.8521	-0.0016	1.9999				19.851	0.164	2.0144	
24	19.8606	-0.0119	1.999				19.859	0.164	2.0138	
25	19.8681	-0.0221	1.9982				19.867	0.164	2.0132	
26	19.8747	-0.0324	1.9975				19.873	0.164	2.0127	
27	19.8806	-0.0425	1.9969				19.879	0.164	2.0122	
28	19.8858	-0.0527	1.9962				19.885	0.164	2.0118	
29	19.8906	-0.0629	1.9957				19.890	0.164	2.0113	
30	19.8948	-0.073	1.9951				19.894	0.163	2.0110	
31	19.8987	-0.0832	1.9946				19.898	0.163	2.0106	

Continued

32	19.9022	-0.0933	1.9942		19.901	0.163	2.0103
33	19.9053	-0.1034	1.9938		19.905	0.163	2.0100
34	19.9082	-0.1135	1.9933		19.907	0.163	2.0097
35	19.9109	-0.1236	1.993		19.910	0.163	2.0094
36	19.9133	-0.1337	1.9926		19.913	0.163	2.0091
37	19.9156	-0.1438	1.9923		19.915	0.163	2.0089
38	19.9176	-0.1538	1.9919		19.917	0.163	2.0086
39	19.9195	-0.1639	1.9916		19.919	0.163	2.0084
40	19.9213	-0.174	1.9913		19.921	0.164	2.0082
41	19.9229	-0.1841	1.9911				
42	19.9244	-0.1941	1.9908				
43	19.9258	-0.2042	1.9905				
44	19.9272	-0.2143	1.9903				
45	19.9284	-0.2244	1.9901				
46	19.9295	-0.2345	1.9899				
47	19.9306	-0.2445	1.9896				
48	19.9316	-0.2546	1.9894				
49	19.9326	-0.2647	1.9893				
50	19.9335	-0.2748	1.9891				
51	19.9343	-0.2849	1.9889				
52	19.9351	-0.295	1.9887				
53	19.9358	-0.3052	1.9886				
54	19.9366	-0.3153	1.9884				
55	19.9372	-0.3254	1.9882				
∞	19.9550		19.9550		19.9550		

Table 7. Resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge Z^* of the $4s^2 4p^2 ({}^2D_2)ns ({}^2S)$ Rydberg series converging to the $({}^2D_2)$ serie limits in Se^{2+} threshold origin $Se^+ 4s^2 4p^3 ({}^2P_{1/2}^o)$ metastable state. The present MOAT calculations are compared to the SCUNC calculations of Sakho *et al.* [11] and the ALS experimental measurements Esteves *et al.* [5]. $|\Delta E|$ denotes the energy difference between the MAOT calculations and the ALS measurement. The resultats are expression in electron-volt (eV). (1 Ryd = 0.5 au = 13.605698 eV).

n	MAOT			ALS			SCUNC			$ \Delta E $
	E	δ	Z^*	E	δ	Z^*	E	δ	Z^*	
6	18.393	0.0971	2.0329	18.393	0.097	2.0329	18.393	0.097	2.0330	0.000
7	18.816	0.0874	2.0253	18.816	0.087	2.0252	18.812	0.099	2.0287	0.000
8	19.0879	0.0774	2.0196	19.077	0.125	2.0317	19.083	0.098	2.0247	0.010
9	19.2729	0.0675	2.0151	19.264	0.125	2.0282	19.269	0.096	2.0216	0.008
10	19.4044	0.0574	2.0115	19.396	0.135	2.0274	19.400	0.095	2.0192	0.008
11	19.5013	0.0473	2.0086	19.495	0.100	2.0230	19.497	0.094	2.0173	0.006

Continued

12	19.5747	0.0371	2.0062	19.571	0.025	2.0168	19.571	0.093	2.0157	0.003
13	19.6316	0.027	2.0042	19.632	-0.100	2.0038	19.628	0.093	2.0144	0.000
14	19.6766	0.0168	2.0024	19.681	-0.150	1.9858	19.674	0.092	2.0133	0.004
15	19.7129	0.0066	2.0009	19.718	-0.240	1.9858	19.710	0.092	2.0123	0.005
16	19.7425	-0.0037	1.9995	19.749	0.097	1.9802	19.740	0.092	2.0115	0.006
17	19.767	-0.0139	1.9984				19.765	0.091	2.0108	
18	19.7875	-0.0242	1.9973				19.785	0.091	2.0102	
19	19.8048	-0.0344	1.9964				19.803	0.091	2.0096	
20	19.8195	-0.0447	1.9955				19.818	0.091	2.0091	
21	19.8322	-0.055	1.9948				19.831	0.091	2.0087	
22	19.8432	-0.0653	1.9941				19.842	0.090	2.0083	
23	19.8528	-0.0756	1.9935				19.851	0.090	2.0079	
24	19.8612	-0.0859	1.9929				19.860	0.090	2.0075	
25	19.8686	-0.0962	1.9923				19.867	0.090	2.0072	
26	19.8751	-0.1065	1.9918				19.874	0.090	2.0069	
27	19.881	-0.1168	1.9914				19.880	0.090	2.0067	
28	19.8862	-0.1271	1.991				19.885	0.090	2.0064	
29	19.8909	-0.1374	1.9906				19.890	0.090	2.0062	
30	19.8951	-0.1477	1.9902				19.894	0.090	2.0060	
31	19.8989	-0.158	1.9899				19.898	0.090	2.0058	
32	19.9024	-0.1683	1.9895				19.902	0.090	2.0056	
33	19.9056	-0.1786	1.9892				19.905	0.090	2.0055	
34	19.9084	-0.189	1.9889				19.908	0.090	2.0053	
35	19.9111	-0.1993	1.9887				19.910	0.090	2.0051	
36	19.9135	-0.2096	1.9884				19.913	0.090	2.0050	
37	19.9157	-0.2199	1.9882				19.915	0.090	2.0049	
38	19.9178	-0.2302	1.988				19.917	0.090	2.0047	
39	19.9197	-0.2406	1.9877				19.919	0.090	2.0046	
40	19.9214	-0.2509	1.9875				19.921	0.090	2.0045	
41	19.923	-0.2612	1.9873							
42	19.9245	-0.2715	1.9872							
43	19.9259	-0.2819	1.987							
44	19.9273	-0.2922	1.9868							
45	19.9285	-0.3025	1.9866							
46	19.9296	-0.3129	1.9865							
47	19.9307	-0.3232	1.9863							
48	19.9317	-0.3335	1.9862							
49	19.9326	-0.3438	1.9861							
50	19.9335	-0.3542	1.9859							
51	19.9344	-0.3645	1.9858							

Continued

52	19.9352	-0.3748	1.9857	
53	19.9359	-0.3852	1.9856	
54	19.9366	-0.3955	1.9855	
55	19.9373	-0.4058	1.9854	
∞	19.9550		19.955	19.955

Table 8. Resonance Energy (En , eV), of the $4s^2 4p^2 ({}^2P_{1/2}^o) nd ({}^1P_1^o)$ Rydberg series of Rb^+ converging to the $(3d^{10} 4s^2 4p^5 2P_{3/2})$ serie limits in Rb^{2+} . The present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [10], the synchrotron radiation (SR) and dual laser plasma (DLP) measurements of Kilbane *et al.* [17] along with their theoretical results from Hartree-Fock with exchange plus relativistic corrections (HXR) [17] and with the Dirac R-matrix calculations of McLaughlin and Babb [18]. $|\Delta E|$ denotes the energy difference between the MAOT calculations and the SR measurement. The results are expression in electron-volt (eV). (1 Ryd = 0.5 au = 13.605698 eV).

$4s^2 4p^2 ({}^2P_{1/2}^o) nd ({}^1P_1^o)$						
Resonance Energie E in eV						
n	MOAT	SCUNC	R-matrix	HXR	SR-DLP	ΔE
8	27.3	27.3000	27.3008	27.3099	27.30	0.0000
9	27.5	27.4949	27.4805	27.4595	27.50	0.0000
10	27.6404	27.6330	27.6223	27.5900	27.63	0.010
11	27.7426	27.7343	27.7263	27.6814	27.74	0.002
12	27.8194	27.8108	27.8046	27.7519	27.82	0.0006
13	27.8786	27.8700	27.8652	27.8072	27.89	0.011
14	27.925	27.9168	27.9129	27.8515	27.95	0.025
15	27.9622	27.9544	27.9512			
16	27.9924	27.9851	27.9824			
17	28.0173	28.0104				
18	28.0381	28.0316				
19	28.0556	28.0495				
20	28.0704	28.0648				
21	28.0831	28.0778				
22	28.0941	28.0892				
23	28.1037	28.0990				
24	28.1121	28.1077				
25	28.1194	28.1153				
26	28.1259	28.1221				
27	28.1317	28.1281				
28	28.1369	28.1334				
29	28.1415	28.1383				
30	28.1457	28.1426				
31	28.1495	28.1465				
32	28.1529	28.1501				
33	28.156	28.1533				

Continued

34	28.1588	28.1563
35	28.1614	28.1590
36	28.1638	28.1615
37	28.1659	28.1638
38	28.1679	28.1659
39	28.1698	28.1678
40	28.1715	28.1696
41	28.1731	
42	28.1746	
43	28.1759	
44	28.1772	
45	28.1784	
∞	28.204	28.204

Table 9. Quantum defect (δ) and effective nuclear charge Z^* of the $4s^2 4p^2 ({}^2P_{1/2}^o) nd ({}^1P_1^o)$ Rydberg series of Rb^+ converging to the $(3d^{10} 4s^2 4p^5 2P_{3/2})$ serie limits in Rb^{2+} . The present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [10] the synchrotron radiation (SR) and dual laser plasma (DPL) measurements of Kilbane *et al.* [17] along with their theoretical results from Hartree-Fock with exchange plus relativistic corrections (HXR) [17] and with the Dirac R-matrix calculations of McLaughlin and Babb [18].

n	Quantum Defects				Effective charge	
	MOAT	SCUNC	R-matrix	HXR	SR-DLP	Z^*
8	0.241	0.2411	0.2376	0.1977	0.1982	2.0621
9	0.2077	0.2391	0.3265	0.2077	0.3922	2.0472
10	0.1736	0.2375	0.3257	0.2628	0.5853	2.0353
11	0.1389	0.2362	0.3253	0.1699	0.7952	2.0256
12	0.1039	0.2351	0.3246	0.0951	1.0283	2.0175
13	0.0685	0.2342	0.3243	-0.1651	1.2887	2.0106
14	0.0329	0.2334	0.3241	-0.6377	1.5846	2.0047
15	-0.0029	0.2327	0.3239			1.9996
16	-0.0389	0.2321	0.3239			1.9951
17	-0.0751	0.2316				1.9912
18	-0.1113	0.2312				1.9877
19	-0.1477	0.2308				1.9846
20	-0.1841	0.2304				1.9818
21	-0.2206	0.2301				1.9792
22	-0.2572	0.2298				1.9769
23	-0.2938	0.2295				1.9748
24	-0.3305	0.2293				1.9728
25	-0.3673	0.2290				1.971
26	-0.404	0.2288				1.9694
27	-0.4408	0.2286				1.9679

Continued

28	-0.4777	0.2285	1.9665
29	-0.5145	0.2283	1.9651
30	-0.5514	0.2281	1.9639
31	-0.5883	0.2280	1.9628
32	-0.6252	0.2279	1.9617
33	-0.6622	0.2277	1.9607
34	-0.6991	0.2276	1.9597
35	-0.7361	0.2275	1.9588
36	-0.7731	0.2274	1.958
37	-0.8101	0.2273	1.9571
38	-0.8471	0.2272	1.9564
39	-0.8842	0.2271	1.9557
40	-0.9212	0.2271	1.955
41	-0.9583		1.9543
42	-0.9953		1.9537
43	-1.0324		1.9531
44	-1.0695		1.9525
45	-1.1066		1.952

Results presented in this table are calculated via Equation (9). The quantum defect and effective nuclear charge Z^* agree well with the MAOT analysis condition of Equation (17). We also note that the quantum defect decreases as the principal quantum number increases. For $n = 11$ up to $n = 23$, the present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [11] and the ALS experimental measurements Esteves *et al.* [5]. The comparison shows very good agreement. $|\Delta E|$ energy differences from experimental data are less than 0.005 eV. For $n = 24$ up to $n = 40$, our results are only compared with SCUNC theoretical calculation of Sakho [11] and comparison is considered very satisfactory. Thus, our value of 19.9391 eV for $n = 40$ is in good agreement with Sakho's calculated result of 19.9391 eV. This allows us to expect the present results on the resonance energies for this Rydberg series up to $n = 55$ to be accurate.

In **Table 3** we present the MAOT, resonance Energy (E_n , eV), quantum defect (δ) and effective nuclear charge (Z^*) of the $4s^2 4p^2 ({}^2D_2) ns ({}^2D_2)$ Rydberg series converging to the $({}^2D_2)$ serie limits in Se^{2+} threshold origin Se^+ $4s^2 4p^3 ({}^2P_{3/2}^o)$ metastable state. Results presented in this table are calculated via Equation (10). The quantum defect and effective nuclear charge Z^* agree well with the MAOT analysis condition of Equation (6). We also note that the quantum defect decreases as the principal quantum number increases. For $n = 7$ up to $n = 23$, Our results are compared with of the experimental data of ALS and those of Sakho (2022) [11] obtained theoretically. The comparison shows very good agree-

ment. The absolute deviations $|\Delta E|$ between MOAT and ALS [5] are small (less than 0.005 eV). For $n = 24$ up to 40, our results are one only compared with SCUNC theoretical calculation of Sakho [11] and comparison is considered very satisfactory. Thus, our value of 21.1425 eV for $n = 40$ is in good agreement with Sakho's calculated result of 21.141 eV. This allows us to expect the present results on the resonance energies for this Rydberg series up to $n = 55$ to be accurate.

In **Table 4** we present the MAOT, resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge (Z^*) of the $4s^2 4p^2 ({}^1D_2) ns$ Rydberg series converging to the (1D_2) serie limits in Se^{2+} threshold origin $Se^+ 4s^2 4p^3 ({}^2P_{1/2}^o)$ metastable state. Results presented in this table are calculated via Equation (11). The quantum defect and effective nuclear charge Z^* agree well with the MAOT analysis condition of Equation (17). We also note that the quantum defect decreases as the principal quantum number increases. For $n = 7$ up to $n = 15$, Our results are compared with of the experimental data of ALS and those of Sakho (2022) obtained theoretically. The comparison shows very good agreement. The absolute deviations $|\Delta E|$ between MOAT and ALS are small, less than 0.001 eV. Thus, our value of 19.7006 eV for $n = 15$ is in good agreement with Sakho's calculated result of 19.697 eV and those of the experimental data of ALS [5] of 19.702 eV. For $n = 16$ up to 40, our results are one only compared with SCUNC théorique calculation of Sakho [11] and comparison is considered very satisfactory. Thus, our value of 19.9213 eV for $n = 40$ is in good agreement with Sakho's calculated result of 19.920 eV. This allows us to expect the present results on the resonance energies for this Rydberg series up to $n = 55$ to be accurate.

We present in **Table 5** resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge (Z^*) of the $4s^2 4p^2 ({}^1D_2) ns$ Rydberg series converging to the (1D_2) serie limits in Se^{2+} threshold origin $Se^+ 4s^2 4p^3 ({}^2P_{3/2}^o)$ metastable state. Results presented in this table are calculated via Equation (12). The quantum defect and effective nuclear charge Z^* agree well with the MAOT analysis condition of Equation (17). We also note that the quantum defect decreases as the principal quantum number increases. For $n = 11$ up to $n = 23$, the present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [11] and the ALS experimental measurements Esteves *et al.* The comparison shows very good agreement. $|\Delta E|$ energy differences from experimental data are less than 0.001 eV. Thus, our value of 19.6943 eV for $n = 15$ is in good agreement with Sakho's calculated result of 19.694 eV and those of the experimental data of ALS [5] of 19.694 eV. For $n = 20$ up to $n = 40$, our results are one only compared with SCUNC theoretical calculation of Sakho and comparison is considered very satisfactory. Thus, our value of 19.8186 eV for $n = 40$ is in good agreement with Sakho's calculated result of 19.818 eV. This allows us to expect the present results on the resonance energies for this Rydberg series up to $n = 55$ to be accurate.

In **Table 6** we present the MAOT, resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge (Z^*) of the $4s^2 4p^2 ({}^1D_2) nd ({}^2P_{1/2}^o)$ Rydberg se-

ries converging to the (1D_2) serie limits in Se^{2+} threshold origin Se^+ $4s^2 4p^3 (^2P_{1/2}^o)$ metastable state. Results presented in this table are calculated via Equation (13). The quantum defect and effective nuclear charge Z^* agree well with the MAOT analysis condition of Equation (17). We also note that the quantum defect decreases as the principal quantum number increases. For $n = 6$ up to $n = 15$, Our results are compared with of the experimental data of ALS and those of Sakho (2022) [11] obtained theoretically. The comparison shows very good agreement. $|\Delta E|$ energy differences from experimental data are less than 0.008 eV. Thus, our value of 19.710 eV for $n = 15$ is in good agreement with Sakho's calculated result of 19.708 eV and those of the experimental data of ALS [5] of 19.718 eV. For $n = 16$ up to $n = 40$, our results are one only compared with SCUNC theoretical calculation of Sakho and comparison is considered very satisfactory. Thus, our value of 19.9213 eV for $n = 40$ is in good agreement with Sakho's calculated result of 19.921 eV. This allows us to expect the present results on the resonance energies for this Rydberg series up to $n = 55$ to be accurate.

We present in **Table 7** resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge (Z^*) of the $4s^2 4p^2 (^2D_2) ns (^2S)$ Rydberg series converging to the (2D_2) serie limits in Se^{2+} threshold origin Se^+ $4s^2 4p^3 (^2P_{1/2}^o)$ metastable state. Results presented in this table are calculated via Equation (14). The quantum defect and effective nuclear charge Z^* agree well with the MAOT analysis condition of Equation (17). We also note that the quantum defect decreases as the principal quantum number increases. For $n = 6$ up to $n = 16$, the present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [11] and the ALS experimental measurements Esteves *et al.* [5]. The comparison shows very good agreement. $|\Delta E|$ energy differences from experimental data are less than 0.008 eV. Thus, our value of 19.7425 eV for $n = 16$ is in good agreement with Sakho's calculated result of 19.740 eV and those of the experimental data of ALS of 19.749 eV. For $n = 17$ up to $n = 40$, our results are one only compared with SCUNC theoretical calculation of Sakho and comparison is considered very satisfactory. Thus, our value of **19.9214** eV for $n = 40$ is in good agreement with Sakho's calculated result of **19.921** eV. This allows us to expect the present results on the resonance energies for this Rydberg series up to $n = 55$ to be accurate.

We present in **Table 8** and **Table 9** resonance Energy (En , eV), quantum defect (δ) and effective nuclear charge (Z^*) of the $4s^2 4p^2 (^2P_{1/2}^o) nd (^1P_1^o)$ Rydberg series of Rb^+ converging to the ($3d^{10} 4s^2 4p^5 2P_{3/2}$) serie limits in Rb^{2+} . Results presented in this table are calculated via Equation (15). The quantum defect and effective nuclear charge Z^* agree well with the MAOT analysis condition of Equation (17). We also note that the quantum defect decreases as the principal quantum number increases. For $n = 8$ up to $n = 14$, the present Modified Atomic Orbital Theory (MOAT) calculations are compared to the SCUNC calculations of Sakho *et al.* [10], the synchrotron radiation (SR) and dual laser plasma (DPL) measurements of Kilbane *et al.* [17] along with their theoretical results from Hartree-Fock

with exchange plus relativistic corrections (HXR) [17] and with the Dirac R-matrix calculations of McLaughlin and Babb [18]. The comparison shows very good agreement. $|\Delta E|$ energy differences from experimental data are less than 0.01 eV. For $n = 15$ up to $n = 40$, our results are one only compared with SCUNC theoretical calculation of Sakho and comparison is considered very satisfactory. This allows us to expect the present results on the resonance energies for this Rydberg series up to $n = 45$ to be accurate.

These strong agreements are justified by the fact that, within the MAOT formalism, σ_i all relativistic and electron-electron correlation effects are implicitly accounted for through the adjustment parameters which are evaluated using experimental data. For all investigated Rydberg series, the slight discrepancies between the present calculations and experimental values may be explained by the inherent simplicity of the MAOT formalism, which does not explicitly incorporate relativistic corrections. The reliability of this extrapolation procedure relies on the asymptotic convergence of the quantum defect, an approach widely validated for the prediction of highly excited Rydberg states [15] [16] [19].

4. Conclusion

In this paper, energy resonances, quantum defects and of the: effective nuclear charge of the $4s^2 4p^2 ({}^3P_2)nd$, $4s^2 4p^2 ({}^1D_2)ns$, $4s^2 4p^2 ({}^2D_2)ns ({}^2D_2)$, $4s^2 4p^2 ({}^1D_2)nd ({}^2P_{1/2}^o)$ and $4s^2 4p^2 ({}^2D_2)ns ({}^2S)$ Rydberg series originating from the $4s^2 4p^3 \left({}^2P_{\frac{1}{2}, \frac{3}{2}}^o \right)$ and $4s^2 4p^3 \left({}^2D_{\frac{3}{2}, \frac{5}{2}}^o \right)$ states of Se^+ and $4s^2 4p^2 ({}^2P_{1/2}^o)nd ({}^1P_1^o)$ Rydberg series of Rb^+ converging to the $(3d^{10} 4s^2 4p^5 2P_{1/2}^o)$ serie limits in Rb^{2+} . Calculations are performed using the Modified Orbital Atomic Atomic Theory (MOAT) semi-empirical procedure for high lying states. Very good agreements with available experimental and theoretical literature data are found. Current calculations provide reference data for the diagnosis and modelling of astrophysical and laboratory plasmas for understanding the chemical evolution of the Se element. The simplicity of the presented procedure, allows to obtain very accurate values of the resonance energies up to highly excited Rydberg states ($n = 55$).

Acknowledgements

The authors are grateful to the Orsay Institute of Molecular Sciences (OIMS), Paris, France and the Abdus Salam International Center for Theoretical Physics (ICTP), Trieste, Italy.

Credit Author Statement

Abdou Faye: Conceptualization; Methodology, Software, Formal analysis, validation, Data curation, Writing-Original draft preparation; Writing-Reviewing and Editing, Validation.

Malick Sow: Conceptualization; Methodology, Formal analysis, validation, Data curation, Writing-Original draft preparation; Writing-Reviewing and Editing, Validation.

Moustapha Kébé: Reviewing; Formal analysis, Validation.

Papa Mamadou Ndiaye; Reviewing; Formal analysis, Validation.

Omar Baba Dia: Reviewing; Formal analysis, Validation.

Cheikh Ndiaye; Reviewing; Formal analysis, Validation.

Cheikh Tidiane Diouf: Reviewing; Formal analysis, Validation.

Oumar Absatou Niass: Reviewing; Formal analysis, Validation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Sterling, N.C. and Dinerstein, H.L. (2008) The Abundances of Light Neutron-Capture Elements in Planetary Nebulae. II. S-Process Enrichments and Interpretation. *The Astrophysical Journal Supplement Series*, **174**, 158-201. <https://doi.org/10.1086/520845>
- [2] Karakas, A.I., van Raai, M.A., Lugaro, M., Sterling, N.C. and Dinerstein, H.L. (2008) Nucleosynthesis Predictions for Intermediate-Mass Asymptotic Giant Branch Stars: Comparison to Observations of Type I Planetary Nebulae. *The Astrophysical Journal*, **690**, 1130-1144. <https://doi.org/10.1088/0004-637x/690/2/1130>
- [3] Langanke, K. and Wiescher, M. (2001) Nuclear Reactions and Stellar Processes. *Reports on Progress in Physics*, **64**, 1657-1701. <https://doi.org/10.1088/0034-4885/64/12/202>
- [4] Macaluso, D.A., Bogolub, K., Johnson, A., et al. (2017) Absolute Single Photoionization Cross-Section Measurements of Rb²⁺ Ions: Experiment and Theory. *Journal of Physics B: Atomic, Molecular and Optical Physics*, **50**, Article 119501. <https://doi.org/10.1088/1361-6455/aa6d1b>
- [5] Esteves, D.A., Bilodeau, R.C., Sterling, N.C., Phaneuf, R.A., et al. (2011) Absolute High-Resolution Se⁺ Photoionization Cross-Section Measurements with Rydberg-Series Analysis. *Physical Review A*, **84**, Article 013406. <https://doi.org/10.1103/physreva.84.013406>
- [6] Esteves, D.A., Aguilar, A., Bilodeau, R.C., Phaneuf, R.A., Kilcoyne, A.L.D., Red, E.C., et al. (2012) Absolute Single Photoionization Cross-Section Measurements of Se³⁺ and Se⁵⁺. *Journal of Physics B: Atomic, Molecular and Optical Physics*, **45**, Article 115201. <https://doi.org/10.1088/0953-4075/45/11/115201>
- [7] Macaluso, D.A., Aguilar, A., Kilcoyne, A.L.D., et al. (2015) Absolute Single-Photoionization Cross-Sections of Se²⁺: Experiment and Theory. *Physical Review A*, **92**, Article 063424. <https://doi.org/10.1103/physreva.92.063424>
- [8] McLaughlin, B.M. and Ballance, C.P. (2012) Photoionization Cross Sections for the Trans-Iron Element Se⁺ from 18 to 31 eV. *Journal of Physics B: Atomic, Molecular and Optical Physics*, **45**, Article 095202. <https://doi.org/10.1088/0953-4075/45/9/095202>
- [9] Sakho, I. and Gning, M.T. (2023) Photoionization Studies of Se²⁺ and S⁴⁺ Ions Using the Screening Constant Per Unit Nuclear Charge Method.
- [10] Sakho, I. (2023) High Lying Precise Resonance Energies from Photoionization Studies of Se³⁺ and Rb⁺ Ions Using the Screening Constant per Unit Nuclear Charge For-

- malism. *Atoms*, **11**, Article 26. <https://doi.org/10.3390/atoms11020026>
- [11] Sakho, I. (2022) Screening Constant per Unit Nuclear Charge Studies of Rydberg Resonances Due to the $4p \rightarrow Nd$ and Ns Transitions in Se^+ Ions. *Atoms*, **10**, Article 107. <https://doi.org/10.3390/atoms10040107>
- [12] Macaluso, D.A., Bogolub, K., Johnson, A., Aguilar, A., Kilcoyne, A.L.D., Bilodeau, R.C., et al. (2016) Absolute Single Photoionization Cross-Section Measurements of Rb^{2+} Ions: Experiment and Theory. *Journal of Physics B: Atomic, Molecular and Optical Physics*, **49**, Article 235002. <https://doi.org/10.1088/0953-4075/49/23/235002>
- [13] Sakho, I. (2013) Photoabsorption of H- and He via the Modified Atomic Orbital Theory: Application to the 1 P-Rydberg State. *Chinese Journal of Physics*, **51**, Article 209.
- [14] Sow, M., Sakho, I., Sow, B., Diouf, A., Gning, Y., et al. (2020) Modified Atomic Orbital Calculations of Energy of the ($2s^2\ ^1S$) Ground-State, the ($2p^2\ ^1D$); ($3d^2\ ^1G$) and ($4f^2\ ^1D$) Doubly Excited States of Helium Isoelectronic Sequence from H^- to Ca^{18+} . *Journal of Applied Mathematics and Physics*, **8**, 85-99. <https://doi.org/10.4236/jamp.2020.81007>
- [15] Faye, A., Sow, M., Kebe, M., Astou, T.N., et al. (2024) Étude de Photoionisation des Singlets [$1s^2 2p(2p3/2)$ Ns 1p, $1s22p(2p)$ Nd 1p, $1s22p(2p1/2)$ Np 1p, $1s22p(2p3/2)$ Np 1d] et des Triplets [$1s22p(2p0)$ Ns 3p0, 1, 2] Série de Rydberg Pour Les Ions Niv via La Théorie Des Orbitales Atomiques Modifiée. *International Journal*, **12**, 1013-1023.
- [16] Sow, M., Ndoye, F., Traoré, A., Diouf, A., Sow, B., Gning, Y. and Diagne, P.A.L. (2021) Photoionization Study of the $2s^2 2p^2(^1D)ns(^2D)$, $2s^2 2p^2(^1D)nd(^2P)$, $2s^2 2p^2(^1D)nd(^2S)$, $2s^2 2p^2(^1S)nd\ ^2D$ and $2s^2 2p^3(^3P)np(^2D)$ Rydberg Series of O^+ Ions via the Modified Atomic Orbital Theory. *Journal of Modern Physics*, **12**, 1375-1386. <https://doi.org/10.4236/jmp.2021.1210086>
- [17] Kilbane, D., Folkmann, F., Bizau, J.M., Banahan, C., Scully, S., Kjeldsen, H., et al. (2007) Absolute Photoionization Cross-Section Measurements of the Kr I Isoelectronic Sequence. *Physical Review A*, **75**, Article 032711. <https://doi.org/10.1103/physreva.75.032711>
- [18] McLaughlin, B.M. and Babb, J.F. (2019) Single Photoionization of the Kr-Like Rb II Ion in the Photon Energy Range 22 - 46.0 eV. *Monthly Notices of the Royal Astronomical Society*, **486**, 245-250. <https://doi.org/10.1093/mnras/stz790>
- [19] Dia, O.B., Sow, M., Kebe, M., Ndiaye, P.M., et al. (2025) Photoionization Study of the $4s^2 4p^4(^3P1)nd$, $4s^2 4p^4(^1D2)nd$ and $4s^2 4p^4(^1S0)nd$ Rydberg Series of Rb^{2+} via the Modified Atomic Orbital Theory. *Journal of Applied Mathematics and Physics*, **13**, 2775-2790. <https://doi.org/10.4236/jamp.2025.138158>
- [20] Moore, C.E. (2022) Atomic Energy Levels. <https://nvlpubs.nist.gov/nistpubs/Legacy/circ/nbscirc467v2.pdf>
- [21] Cowan, R.D. (2022) The Theory of Atomic Structure and Spectra. <https://www.ucpress.edu/book/9780520038219/the-theory-of-atomic-structure-and-spectra>