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HİDROJEN BENZERİ NOBELYUMUN ELEKTRİK DİPOL GEÇİŞLERİ

Güldem ÜRER *(gurer@sakarya.edu.tr)*

Sakarya Üniversitesi, Fizik Bölümü

ÖZET

Büyük atom numaralı iyonlarla çalışmak atomun yapısını anlamak ve atomik yapıyı tanımlamada kullanılan yöntemleri test etmek için bir fırsattır. Astrofiziksel spektrumu yorumlama, atomik çarpışma çalışmaları, X-ışını lazerleri gibi birçok çalışma geçiş parametrelerinin doğru verilerine ihtiyaç duyar. Bu ihtiyaç, hidrojen benzeri nobelyumun (No101+, Z=102) elektrik dipol geçişleri için daha hassas atomik verilerinin sağlanmasının sebebidir. No101+'nın nl (n=1-9 and l=0-4) seviyeleri arasındaki geçişlerinin dalga boyları, logaritmik ağırlıklı salınıcı şiddetleri ve geçiş olasılıkları, relativistik çok konfigürasyonlu Hartree-Fock (MCHF) ve tam relativistik Dirac-Fock (MCDF) yöntemleriyle elde edilmektedir. Elde edilen sonuçlar literatürde mevcut olan tek çalışmayla karşılaştırılmaktadır.

Anahtar kelimeler: *MCHF yöntemi, MCDF yöntemi, Geçiş parametreleri*

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THE ELECTRIC DIPOLE TRANSITIONS OF HYDROGEN LIKE NOBELIUM

Güldem ÜRER *(gurer@sakarya.edu.tr)*

Sakarya University, Department of Physics

ABSTRACT

It is an occasion to understand and test the methods for determination of atomic structure on hydrogen like ions especially with high atomic number, Z. Many studies such as interpretation of astrophysical spectra and atomic collision studies, the development of X-ray lasers etc. demand exact transition parameters data. This need is a reason of the present paper to support more precise atomic data of electric dipole transitions parameters for hydrogen like nobelium (No101+, Z=102). The wavelengths, logarithmic weighted oscillator strengths and transition probabilities of No101+ have been reproduced with relativistic multiconfiguration Hartree-Fock (MCHF) and fully relativistic multiconfiguration Dirac-Fock (MCDF) methods. The transitions between nl (n=1-9 and l=0-4) levels have been investigated in this work. The results obtained have been compared with a unique theoretical work in available literature.

Keywords: *MCHF method, MCDF method, Transitions parameters*

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1. INTRODUCTION

The developing technology requires precise knowledge of wavelengths, oscillator strengths, and transition probabilities for highly charged ions. It is great needs for interpretation of astrophysical spectra and atomic collision studies, the development of X-ray lasers and the diagnostics of fusion plasmas etc. [1]. The sensitive calculation of level structure is the initial step of the precise description spectral characteristics. The studies on highly ionized atoms have been performed many times, even for hydrogen like ions with high Z. They are listed in NIST atomic data base [2]. On the other hand, the studies containing data for hydrogen like nobelium, No^{101+}, is so sparse. Thus, a study has been performed in high accuracy for level structure of No^{101+} [3]. This work has extended for transition parameters using mentioned high accuracy level structure data. The unique theoretical data for transition parameters of No^{101+} belongs to Jitrik and Bunge [4 and 5]. They have published two papers about calculations using point-nucleus Dirac eigenfunctions which contains *nl* (n=1-26, l=0-25) levels with $1 \leq Z \leq 118$. These works are available on a web site [6]. This lack has led to perform present work as a part of three, two, and one electron actinides investigation [7, 8, and 9]. It is important the supporting theoretical data with experimental one. Unfortunately, there is not any experimental one for No^{101+} because of its radioactivity and short lifetimes.

The wavelengths, weighted oscillator strengths, and transition probabilities are computed for electric dipole, quadrupole and magnetic dipole transitions between *nl* (n=1-9, l=0-4) levels of No^{101+}. In the calculation MCHF atomic structure package [10] (multiconfiguration Hartree-Fock, MCHF, approximation) and GRASP [11] (multiconfiguration Dirac-Fock, MCDF, method) have been used. It is important to remember that some of the relativistic effects for large Z need to be attributed to the account.

The Breit-Pauli effects are included for MCHF approximation and the transverse photon and quantum electrodynamics (QED consists of self energy plus vacuum polarization) considered for MCDF calculation. Furthermore, correlation effects have been also included in both methods.

2. BASIC FORMULAS OF CALCULATION

The only basic formulas of multiconfiguration Hartree-Fock (MCHF) and multiconfiguration Dirac-Fock (MCDF) method have here mentioned for the brevity. The detailed description of both methods can be found [10 and 12] for MCHF and [11 and 13], for MCDF method.

In the MCHF approximation, the wavefunction, $\Psi(\gamma LS)$,is generated with a linear combination of $\Phi(\gamma_i LS)$ configuration state functions (,CSFs)

$$\Psi(\gamma LS)=\sum_{i=1}^{M} c_i \Phi(\gamma_i LS) \qquad \sum_{i=1}^{M} c_i^2 = 1 \tag{1}$$

It is changed by an atomic state functions (ASF) which contains total angular momenta *J* in fully relativistic method

$$\Psi_\alpha(PJM)=\sum_{r}^{n_c} c_r(\alpha)\left|\gamma_r PJM\right\rangle \tag{2}$$

In the MCHF method, the beginning hamiltonian is non-relativistic one

$$H_{NR}=\sum_{j=1}^{N}\left(\frac{1}{2}\nabla_j^2-\frac{Z}{r_j}\right)+\sum_{j<k}\frac{1}{r_{jk}} \tag{3}$$

.

The first order (α^2) corrections in the Breit-Pauli Hamiltonian are evaluated by perturbation. The Breit-Pauli Hamiltonian consists of

mass correction, Darwin corrections, spin-orbit, spin-other orbit, orbit-orbit, spin-spin contact terms.

The energy functional in the MCDF method based on the Dirac-Coulomb Hamiltonian,

$$H_{DC} = \sum_{j=1}^{N} \left(c\vec{\alpha}_j . \vec{p}_j + (\beta_j - 1)c^2 + V\left(r_j\right) \right) + \sum_{j<k}^{N} \frac{1}{r_{jk}} . \quad (4)$$

The considered corrections are the transverse photon (Breit) interaction and the QED corrections (self-energy plus vacuum polarization) in the MCDF method.

The two-component Fermi function for nuclear charge distribution is used and correlation effects are also considered in both methods.

A characterization of a transition between two states is described by the angular momentum and parity of the corresponding photon. The parity is $\pi = (-1)^k$ of electric multipole (E*k*) or $\pi = (-1)^{k+1}$ is magnetic multipole (M*k*) for a transitional photon. Here, *k* is the angular momentum of an emitted or observed photon. A radiative emission transition probability is given by

$$A^{\pi k}\left(\gamma' J', \gamma J\right) = 2C_k \left[\alpha \left(E_{\gamma' J'} - E_{\gamma J} \right) \right]^{2k+1} \frac{S^{\pi k}(\gamma' J', \gamma J)}{g_{J'}} . \quad (5)$$

3. RESULTS AND DISCUSSION

Hydrogen like works has been performed in high accuracy a lot of time for low and mid-Z ions. There were some restrictive subjects such as memory and convergence for high Z. The developing computer hardware and programs have overcome these problems. Despite all these, there are still very few theoretical structural studies on actinide elements, which are mostly synthetic, today and the existing studies are not sensitive enough. This work has described a part of large-scaled work done about hydrogen, helium and lithium like actinide ions to overcome the shortcoming

mentioned above. The investigation for energy levels of *nl* (*n*=1-9 and *l*=0-4) hydrogen like nobelium (No^{101+}, Z=102) have been presented another work [3]. The structure work has expanded for transitions of No^{101+} because the former study has correctly predicted the energy levels.

The allowed (electric dipole, E1) and forbidden (electric dipole, E2, and magnetic dipole, M1) transitions parameters between *nl* (*n*=1-9, *l*=0-4) levels of No^{101+} have been calculated. The multiconfiguration Hartree-Fock (MCHF) and multiconfiguration Dirac-Fock (MCDF) methods have been applied to subject. MCHF atomic structure package [10] for an implementation of MCHF approximation and GRASP [11] which is an application of MCDF method, have used for calculations. It is an indisputable reality that contributions have to consider in calculations. The Breit-Pauli corrections for MCHF the transverse photon and quantum electrodynamic (QED is self energy plus vacuum polarization) effects for MCDF have been included in the calculations besides correlations.

The numbers of E1, E2 and M1 transitions are 528, 649 and 174 for MCHF and 528, 668, and 504 for MCDF, respectively. Wavelengths, weighted oscillator strengths and transition probabilities have computed for all transitions. All possible electric dipole, quadrupole and magnetic dipole transitions between *nl* (*n*=1-9, *l*=0-4) levels are too much for this paper. In Table 1, the electric dipole transition to ground state, $1s_{1/2}$, of No^{101+} have been given comparing with other unique work [6] in available literature. The new electric dipole transition parameters for No^{101+} have been presented in Table 2. Unfortunately, there is no available experimental data for E1, E2, and M1 transitions of No^{101+}. All E1, E2, and M1 transitions can be obtained from the corresponding author. The MCHF atomic structure package compute the transition parameters in Babushkin gauge. In the MCDF calculation

weighted oscillator strengths and transition probabilities for E1, E2 transitions, are calculated in both Coulomb (velocity) and Babushkin (length) gauges. It is a so important point that conformity between two gauges a sign for precision of calculation [12].

In Table 1, it is seen an agreement for wavelengths. The small differences between the results from MCHF and MCDF have come from involving different contributions. The MCDF method has the transverse photon and quantum electrodynamic contributions while the MCHF has only Breit-Pauli relativistic contributions. The average percentage error of MCDF results 0.23%, as it is 13.60% for MCHF results with other work [6]. The average between results (MCHF-MCDF) is 6.72%. The supporting methods to each other is proof these methods are suitable for calculation of No^{101+}. In Jitrik and Bunge's work [6], the energy values of nl_j are those of same $n(l+1)_j$ (for example, $E(2s_{1/2})=E(2p_{1/2})=1\ 035\ 901\ 070.60\ cm^{-1}$, $E(3p_{3/2})=E(3d_{3/2})=1\ 267\ 045\ 360.80\ cm^{-1}$ and $E(4d_{5/2})=E(4f_{5/2})=1\ 328\ 686\ 355{,}50\ cm^{-1}$ etc.). It has proved that the present calculations especially MCDF results is the most accurate and reliable data ever have done. Moreover, Figure 1 has presented to show agreement between present and other work [6]. The linear correlation coefficient R^2 is 1.0000 for MCDF method, as R^2 of MCHF calculation is 0.8591. It has clearly appeared that MCHF, and especially MCDF results are trustable results than other works. It has been not possible to draw a suitable graphic log *gf*-value and A_{ki} because of that the scales of these parameters are too large. The rate gauges of MCDF calculation has been 1.03 for logarithmic gf-values and transition probabilities of E1 transitions. On the other hand, the agreement between MCHF and MCDF methods has reduced for $ns_{1/2}$-$np_{1/2}$, $nd_{3/2}$-$np_{3/2}$, $nd_{5/2}$-$nf_{5/2}$ and $nf_{7/2}$-$ng_{7/2}$ n=2-7 electric dipole transitions. However, the MCDF results are considered to be more reliable for these transitions.

The comments mentioned before for E1 have also been true for E2 and M1 transitions. The understanding lines in astrophysical objects, plasma modelling and solar physics, need to radiative transition data. Especially, the study of forbidden transitions can bring valuable in the astronomical spectra transitions from metastable levels occur at much longer wavelengths than other transitions in the same ion [14].

The comparisons for transition parameters could be made with the work have theoretically studied by Jitrik and Bunge [6], the only source in the literature. There is no experimental study available in the accessible literature. In general, the compatibility between MCHF-MCDF and MCDF Coulomb and Babushkin gauges as well as the results are consistent with the results of other studies, proves that a successful study has been carried out. Thus, many transition parameters have presented for the first time. The wavelengths, weighted oscillator strengths and transition parameters of $ns_{1/2}$-$np_{1/2}$, $np_{3/2}$-$nd_{3/2}$, $nd_{5/1}$-$nf_{5/2}$, $nf_{7/2}$-$g_{7/2}$ (n=2-9), $ng_{7/2}$-$n'_{=5/2}$ (n=5, 6, 7 n'=8, 9), $ng_{9/2}$-$n'_{=7/2}$ (n=5, 6, 7 n'=8, 9) for E1, $4d_{5/2}$-$5s_{1/2}$, $6s_{1/2}$, $ng_{7/2}$-$n'd_{3/2,5/2}$ (n=5, 6, 7 n'=8, 9), $ng_{9/2}$-$n'd_{5/2}$ (n=8, 9), $6g_{7/2}$-$7d_{3/2}$ for E2, and $ng_{7/2}$-$n'd_{5/2}$(n=5, 6; n'=8, 9), $7s_{1/2}$-$8s_{1/2}$, $9s_{1/2}$-$9d_{3/2}$ for M1, are new for literature. Furthermore, all 8g and 9g transitions for E1, E2, and M1 and *gf*-values E2 and M1 transitions are represented for the first time.

Table 1. Wavelengths, λ (Å), logarithmic *gf*-values, Log *gf*-values, and transition probabilities, A_{ki}, (s^{-1}) for electric dipole (E1) transitions in No^{101+}. "A", "B" and "C" respect the results from MCHF, MCDF according to Babushkin gauge and MCDF according to Coulomb gauge, respectively. The MCDF wavelengths results have been indicated only B because wavelengths are not dependent on the gauges. Comparison for results have been made with reference [6].

Other work results have been remarked with "*".

Transitions	**λ (Å)**	**Log *gf*-values**	**A_{ki} (s^{-1})**
$1s_{1/2}$ - $2p_{1/2}$	1.00(-1)[A]	-8.32(-1)[A]	4.63394(16)[A]
	9.9412433(-2)[B]	-6.3934(-1)[C]	7.7426117(16)[C]
	9.888293(-2)*	-66907(-1)[B]	7.2303668(16)[B]
		-6.75490(-1)*	7.2007(16)*
$1s_{1/2}$ - $3p_{1/2}$	9.00(-2)[A]	-2.2531[A]	2.55255(15)[A]
	8.2846092(-2)[B]	-1.41407[C]	1.8728464(16)[C]
	8.213641(-2)*	-1.52177[B]	1.4614953(16)[B]
		-1.51833*	1.4987(16)*
$1s_{1/2}$ - $4p_{1/2}$	8.00(-2)[A]	-6.714[A]	9.84264(10)[A]
	7.8353018(-2)[B]	-1.87925[C]	7.1738599(15)[C]
	7.771385(-2)*	-2.01078[B]	5.2993360(15)[B]
		-2.00474*	5.4623(15)*

$1s_{1/2}$ - $5p_{1/2}$	8.00(-2)[A]	-2.94396[A]	6.07091(14)[A]
	7.6501588(-2)[B]	-2.2213[C]	3.4234834(15)[C]
	7.589074(-2)[*]	-2.36096[B]	2.4820406(15)[B]
		-2.35006[*]	2.5863(15)[*]
$1s_{1/2}$ - $6p_{1/2}$	8.00(-2)[A]	-2.48626[A]	1.78408(15)[A]
	7.5558029(-2)[B]	-2.49595[C]	1.8646850(15)[C]
	7.496154(-2)[*]	-2.63944[B]	1.3400249(15)[B]
		-2.61927[*]	1.4262(15)[*]
$1s_{1/2}$ - $7p_{1/2}$	8.00(-2)[A]	-2.19159[A]	3.56644(15)[A]
	7.5011587(-2)[B]	-2.71772[C]	1.1353706(15)[C]
	7.442344(-2)[*]	-2.87547[B]	7.8956024(14)[B]
		-2.84055[*]	8.6925(14)[*]
$1s_{1/2}$ - $8p_{1/2}$	8.00(-2)[A]	-1.89129[A]	7.18533(15)[A]
	7.4666621(-2)[B]	-2.92832[C]	7.0556300(14)[C]
	7.408381(-2)[*]	-3.08743[B]	4.8913349(14)[B]
		-3.02871[*]	5.6880(14)[*]

Table 1. Continued

Transitions	λ (Å)	Log *gf*-values	A_{ki}, (s^{-1})
$1s_{1/2}$ - $9p_{1/2}$	8.00(-2)[A]	-1.4348[A]	2.06824(16)[A]
	7.4434702(-2)[B]	-3.13919[C]	4.3689155(14)[C]
	7.385568(-2)[*]	-3.2991[B]	3.0231414(14)[B]
		-3.19254[*]	3.9247(14)[*]
$1s_{1/2}$ - $2p_{3/2}$	1.00(-1)[A]	-5.2617(-1)[A]	5.14103(16)[A]
	9.4107629(-2)[B]	-6.4415(-1)[C]	4.2725239(16)[C]
	9.319273(-2)[*]	-5.2323(-1)[B]	5.6442246(16)[B]
		-2.29700(-1)[*]	5.6570(16)[*]
$1s_{1/2}$ - $3p_{3/2}$	8.00(-2)[A]	-1.50299[A]	7.30113(15)[A]
	8.1606022(-2)[B]	-1.29674[C]	1.2644541(16)[C]
	8.091185(-2)[*]	-1.18287[B]	1.6434894(16)[B]
		-8.83590(-1)[*]	1.6651(16)[*]
$1s_{1/2}$ - $4p_{3/2}$	8.00(-2)[A]	-2.54597[A]	7.28488(14)[A]
	7.7888885(-2)[B]	-1.71525[C]	5.2951628(15)[C]
	7.725510(-2)[*]	-1.60721[B]	6.7908953(15)[B]
		-1.30555[*]	6.9128(15)[*]
$1s_{1/2}$ - $5p_{3/2}$	8.00(-2)[A]	-4.01966[A]	2.55558(13)[A]
	7.6278143(-2)[B]	-2.02529[C]	2.7039002(15)[C]
	7.566981(-2)[*]	-1.92567[B]	3.4010864(15)[B]

			-1.61986*	3.4942(15)*
$1s_{1/2}$	- $6p_{3/2}$	8.00(-2)A	-2.54856A	7.73681(14)A
		7.5433470(-2)B	-2.28073C	1.5354277(15)C
		7.483834(-2)*	-2.18498B	1.9141510(15)B
			-1.87123*	2.0025(15)*
$1s_{1/2}$	- $7p_{3/2}$	8.00(-2)A	-2.05562A	2.44019(15)A
		7.4935115(-2)B	-2.52361C	8.8940234(14)C
		7.434776(-2)*	-2.4075B	1.1620250(15)B
			-2.08106*	1.2516(15)*
$1s_{1/2}$	- $8p_{3/2}$	8.00(-2)A	-1.65573A	6.18195(15)A
		7.4616348(-2)B	-2.72425C	5.6515001(14)C
		7.403400(-2)*	-2.6086B	7.3759461(14)B
			-2.26129*	8.3349(14)*
$1s_{1/2}$	- $9p_{3/2}$	8.00(-2)A	-1.12074A	2.13159(16)A
		7.4399946(-2)B	-2.92594C	3.5727399(14)C
		7.382116(-2)*	-2.81018B	4.6639472(14)B
			-2.41933*	5.8259(14)*

Table 2. New electric dipole transition parameters (Wavelengths, λ (Å), logarithmic gf-values, Log *gf*-values, and transition probabilities, A_{ki}, (s^{-1})) for No^{101+}. [A]: MCHF results. [B]: MCDF according to Babushkin gauge. [C]: MCDF according to Coulomb gauge. The MCDF wavelengths results have been indicated only "[B]" because wavelengths are not dependent on the gauges

Transitions	λ (Å)	Log *gf*-values	A_{ki} (s^{-1})
$2s_{1/2}$ - $2p_{1/2}$	9.75[A]	-1.35717[A]	1.54042(12)[A]
	3.3798857(1)[B]	-3.01352[C]	2.8300406(9)[C]
		-2.07367[B]	2.4639716(10)[B]
$3s_{1/2}$ $3p_{1/2}$	4.59(1)[A]	-1.22386[A]	9.46200(10)[A]
	1.8457050(2)[B]	-2.41726[C]	3.7456404(8)[C]
		-1.94771[B]	1.1042810(9)[B]
$3p_{3/2}$ - $3d_{3/2}$	2.97(2)[A]	-2.62332[A]	4.50012(7)[A]
	2.9494960(3)[B]	-4.73905[C]	3.4957500(3)[C]
		-3.64133[B]	4.3778537(4)[B]
$4s_{1/2}$ - $4p_{1/2}$	1.41(2)[A]	-1.17013[A]	1.14047(10)[A]
	4.4845156(2)[B]	-2.27178[C]	8.8696347(7)[C]
		-1.76683[B]	2.8369603(8)[B]
$4p_{3/2}$ - $4d_{3/2}$	6.09(2)[A]	-2.29073[A]	2.30442(7)[A]
	7.0218040(3)[B]	-3.6288[C]	7.9503505(3)[C]
		-3.3726[B]	1.4341183(4)[B]
$4d_{5/2}$ - $4f_{5/2}$	3.26(3)[A]	-3.4391[A]	3.80102(4)[A]

	4.0128892(6)[B]	-1.47723[C]	2.3006376[C]
		-6.53494[B]	2.0143620(-5)[B]
$4f_{5/2}$ - $8g_{7/2}$	1.82[A]	-0.8642[A]	3.42793(13)[A]
	1.8243794[B]	-0.81268[C]	3.8560338(13)[C]
		-0.80946[B]	3.8847764(13)[B]
$4f_{5/2}$ - $9g_{7/2}$	1.71[A]	-1.2517[A]	1.60579(13)[A]
	1.7061749[B]	-1.10774[C]	2.2349325(13)[C]
		-1.10135	2.2680945(13)
$4f_{7/2}$ - $8g_{7/2}$	1.85[A]	-2.3337[A]	1.12621(12)[A]
	1.8535200[B]	-2.2954[C]	1.2292895(12)[C]
		-2.29283[B]	1.2366117(12)[B]
$4f_{7/2}$ - $9g_{7/2}$	1.73[A]	-2.68732[A]	5.71564(11)[A]
	1.7316353[B]	-2.59412[C]	7.0797193(11)[C]
		-2.5898[B]	7.1506024(11)[B]
$4f_{7/2}$ - $8g_{9/2}$	1.85[A]	-0.73644[A]	3.57189(13)[A]
	1.8513334[B]	-0.71329[C]	3.7659980(13)[C]
		-0.70985[B]	3.7959554(13)[B]

Table 2.
Continued

Transitions	λ (Å)	Log *gf*-values	A_{ki} (s^{-1})
$4f_{7/2}$ - $9g_{9/2}$	1.73[A]	-1.07322[A]	1.88285(13)[A]
	1.7302965[B]	-1.01009[C]	2.1767510(13)[C]
		-1.00312[B]	2.2119912(13)[B]
$5s_{1/2}$ - $5p_{1/2}$	3.36(2)[A]	-1.13835[A]	2.14986(9)[A]
	9.0260576(2)[B]	-2.25078[C]	2.2979067(7)[C]
		-1.64598[B]	9.2498844(7)[B]
$5d_{3/2}$ - $5p_{3/2}$	1.21(3)[A]	-2.14338[A]	8.18728(6)[A]
	1.3757072(4)[B]	-2.75678[C]	1.5426108(4)[C]
		-3.21806[B]	5.3329541(3)[B]
$5f_{5/2}$ - $5d_{5/2}$	4.30(3)[A]	-2.99971[A]	6.00400(4)[A]
	1.3032769(6)[B]	-1.15101[C]	4.6228885(1)[C]
		-5.48785[B]	2.1284977(-3)[B]
$5f_{5/2}$ - $8g_{7/2}$	3.50[A]	-0.34604[A]	3.07202(13)[A]
	3.4972467[B]	-0.31319[C]	3.3144220(13)[C]
		-0.30895[B]	3.3469664(13)[B]
$5f_{5/2}$ - $9g_{7/2}$	3.09[A]	-0.75252[A]	1.54626(13)[A]
	3.0872390[B]	-0.65352[C]	1.9426455(13)[C]
		-0.64758[B]	1.9694175(13)[B]

$5f_{7/2}$ - $5g_{7/2}$	2.07(4)[A]	-4.05821[A]	1.70716(2)[A]
	1.4068612(6)[B]	-1.75492[C]	7.4068216[C]
		-5.89362[B]	5.3818293(-4)[B]
$5f_{7/2}$ - $8g_{7/2}$	3.55[A]	-1.79093[A]	1.06991(12)[A]
	3.5524298[B]	-1.76631[C]	1.1315889(12)[C]
		-1.76229[B]	1.1421216(12)[B]
$5f_{7/2}$ - $9g_{7/2}$	3.13[A]	-2.17988[A]	5.62713(11)[A]
	3.1301622[B]	-2.11413[C]	6.5431616(11)[C]
		-2.10805[B]	6.6354625(11)[B]
$5f_{7/2}$ - $8g_{9/2}$	3.54[A]	-0.21917[A]	3.20610(13)[A]
	3.5444066[B]	-0.20527[C]	3.3097105(13)[C]
		-0.20093[B]	3.3428998(13)[B]
$5f_{7/2}$ - $9g_{9/2}$	3.13[A]	-0.59219[A]	1.74613(13)[A]
	3.1257904[B]	-0.54796[C]	1.9331506(13)[C]
		-0.54174[B]	1.9610334(13)[B]
$5g_{7/2}$ - $8f_{5/2}$	3.56[A]	-3.20331[A]	5.48885(10)[A]
	3.5661179[B]	-2.3832[C]	3.6174481(11)[C]
		-2.43908[B]	3.1807215(11)[B]
$5g_{7/2}$ - $9f_{5/2}$	3.13[A]	-3.04004[A]	1.03228(11)[A]
	3.1375836[B]	-2.74786[C]	2.0180919(11)[C]
		-2.87823[B]	1.4947658(11)[B]

$5g_{7/2}$ - $8f_{7/2}$	3.55[A]	-4.87267[A]	8.86841(8)[A]
	3.5523660[B]	-3.93818[C]	7.6179789(9)[C]
		-4.00253[B]	6.5688248(9)[B]
$5g_{7/2}$ - $9f_{7/2}$	3.13[A]	-4.34783[A]	3.82410(9)[A]
	3.1301146[B]	-4.2997[C]	4.2680518(9)[C]
		-4.45971[B]	2.9527251(9)[B]
$5g_{9/2}$ - $8f_{7/2}$	3.58[A]	-2.7303[A]	1.20805(11)[A]
	3.5854274[B]	-2.31725[C]	3.1240692(11)[C]
		-2.37604[B]	2.7285672(11)[B]
$5g_{9/2}$ - $9f_{7/2}$	3.15[A]	-4.74699[A]	1.50037(9)[A]
	3.1557551[B]	-2.68225[C]	1.7401957(11)[C]
		-2.82105[B]	1.2641502(11)[B]
$6s_{1/2}$ - $6p_{1/2}$	6.90(2)[A]	-1.11924[A]	5.31829(8)[A]
	1.6191466(3)[B]	-2.38169[C]	5.2826727(6)[C]
		-1.55918[B]	3.5104492(7)[B]
$6d_{3/2}$ - $6p_{3/2}$	2.23(3)[A]	-2.06018[A]	2.92630(6)[A]
	2.3652554(4)[B]	-2.01054[C]	2.9092688(4)[C]
		-3.10507[B]	2.3402210(3)[B]
$6f_{5/2}$ - $6d_{5/2}$	6.58(3)[A]	-2.79326[A]	4.13080(4)[A]
	5.1090575(5)[B]	-0.91712[C]	5.1545914(2)[C]
		-4.69119[B]	8.6719781(-2)[B]

$6f_{5/2}$ - $8g_{7/2}$	7.00^{A}	0.124188^{A}	$2.26677(13)^{A}$
	6.9879200^{B}	0.13935^{C}	$2.3534649(13)^{C}$
		0.144545^{B}	$2.3817835(13)^{B}$
$6f_{5/2}$ - $9g_{7/2}$	5.53^{A}	-0.34957^{A}	$1.21991(13)^{A}$
	5.5224547^{B}	-0.28714^{C}	$1.4114099(13)^{C}$
		-0.28172^{B}	$1.4291205(13)^{B}$
$6f_{7/2}$ - $8g_{7/2}$	7.11^{A}	-1.29991^{A}	$8.25707(11)^{A}$
	7.1159964^{B}	-1.28794^{C}	$8.4847172(11)^{C}$
		-1.2828^{B}	$8.5858837(11)^{B}$
$6f_{7/2}$ - $9g_{7/2}$	5.60^{A}	-1.76895^{A}	$4.52402(11)^{A}$
	5.6021388^{B}	-1.72667^{C}	$4.9851323(11)^{C}$
		-1.72058^{B}	$5.0555009(11)^{B}$
$6f_{7/2}$ - $8g_{9/2}$	7.09^{A}	0.251339^{A}	$2.36982(13)^{A}$
	7.0838755^{B}	0.256013^{C}	$2.3967031(13)^{C}$
		0.261267^{B}	$2.4258773(13)^{B}$
$6f_{7/2}$ - $9g_{9/2}$	5.59^{A}	-0.2006^{A}	$1.34514(13)^{A}$
	5.5881508^{B}	-0.17485^{C}	$1.4280870(13)^{C}$
		-0.16897^{B}	$1.4475586(13)^{B}$
$6g_{7/2}$ - $8f_{5/2}$	7.15^{A}	-1.73775^{A}	$3.97249(11)^{A}$
	7.1710762^{B}	-1.44522^{C}	$7.7554126(11)^{C}$
		-1.49758^{B}	$6.8745289(11)^{B}$

$6g_{7/2}$ - $9f_{5/2}$	5.62[A]	-4.06841[A]	3.01121(9)[A]
	5.6259200[B]	-1.92379[C]	4.1861601(11)[C]
		-2.07933[B]	2.9259979(11)[B]
$6g_{7/2}$ - $6f_{7/2}$	1.98(4)[A]	-3.52949[A]	6.30599(2)[A]
	5.4861585(5)[B]	-1.23822[C]	1.6006560(2)[C]
		-4.97636[B]	2.9251784(-2)[B]
$6g_{7/2}$ - $8f_{7/2}$	7.11[A]	-3.28729[A]	8.51014(9)[A]
	7.1156839[B]	-2.98902[C]	1.6888998(10)[C]
		-3.04952[B]	1.4692649(10)[B]
$6g_{7/2}$ - $9f_{7/2}$	5.60[A]	-8.08807[A]	2.17144(5)[A]
	5.6019514[B]	-3.4631[C]	9.1469957(9)[C]
		-3.65099[B]	5.9345039(9)[B]
$6g_{9/2}$ - $8f_{7/2}$	7.19[A]	-1.55685[A]	4.47835(11)[A]
	7.1928690[B]	-1.37544[C]	6.7889757(11)[C]
		-1.43027[B]	5.9838036(11)[B]
$6g_{9/2}$ - $9f_{7/2}$	5.65[A]	-2.69893[A]	5.23130(10)[A]
	5.6496799[B]	-1.85282[C]	3.6659022(11)[C]
		-2.01817[B]	2.5051828(11)[B]
$7s_{1/2}$ - $7p_{1/2}$	1.29(3)[A]	-1.11111[A]	1.54425(8)[A]
	2.6736826(3)[B]	-2.77021[C]	7.9192406(5)[C]
		-1.49204[B]	1.5026483(7)[B]

$7d_{3/2}$	- $7p_{3/2}$	3.86(3)[A]	-2.00969[A]	1.09675(6)[A]
		3.6539915(4)[B]	-1.44759[C]	4.4561300(4)[C]
			-3.00622[B]	1.2311981(3)[B]
$7d_{5/2}$	- $7f_{5/2}$	1.02(4)[A]	-2.67296[A]	2.27747(4)[A]
		3.1304135(5)[B]	-0.64543[C]	2.5665987(3)[C]
			-4.17003[B]	7.6693425(-1)[B]
$7f_{5/2}$	- $8g_{7/2}$	1.76(1)[A]	0.760551[A]	1.54570(13)[A]
		1.7556467(1)[B]	0.755816[C]	1.5416827(13)[C]
			0.762062[B]	1.5640148(13)[B]
$7f_{5/2}$	- $9g_{7/2}$	1.06(1)[A]	0.092187[A]	9.24579(12)[A]
		1.0533649(1)[B]	0.121297[C]	9.9355584(12)[C]
			0.128213[B]	1.0095066(13)[B]
$7f_{7/2}$	- $8g_{7/2}$	1.81(1)[A]	-0.63506[A]	5.91372(11)[A]
		1.8071102(1)[B]	-0.63491[C]	5.9179456(11)[C]
			-0.62874[B]	6.0026199(11)[B]
$7f_{7/2}$	- $9g_{7/2}$	1.07(1)[A]	-1.31737[A]	3.49527(11)[A]
		1.0716763(1)[B]	-1.29713[C]	3.6626153(11)[C]
			-1.28914[B]	3.7306268(11)[B]
$7f_{7/2}$	- $8g_{9/2}$	1.79(1)[A]	0.891433[A]	1.62344(13)[A]
		1.7865382(1)[B]	0.886372[C]	1.6087569(13)[C]
			0.892611[B]	1.6320356(13)[B]

$7f_{7/2}$ - $9g_{9/2}$	1.07(1)[A]	0.233362[A]	1.00170(13)[A]
	1.0665690(1)[B]	0.241126[C]	1.0216262(13)[C]
		0.248623[B]	1.0394136(13)[B]
$7g_{7/2}$ - $8f_{5/2}$	1.83(1)[A]	-0.53354[A]	9.67709(11)[A]
	1.8430152(1)[B]	-0.42139[C]	1.2403363(12)[C]
		-0.45778[B]	1.1406557(12)[B]
$7g_{7/2}$ - $9f_{5/2}$	1.08(1)[A]	-1.72916[A]	1.78725(11)[A]
	1.0803974(1)[B]	-1.17332[C]	6.3900424(11)[C]
		-1.31131[B]	4.6506563(11)[B]
$7g_{7/2}$ - $7f_{7/2}$	2.51(4)[A]	-3.27741[A]	7.00022(2)[A]
	3.1826932(5)[B]	-0.82143[C]	1.2417524(3)[C]
		-4.38556[B]	3.3877256(-1)[B]
$7g_{7/2}$ - $8f_{7/2}$	1.81(1)[A]	-2.06734[A]	2.19108(10)[A]
	1.8068656(1)[B]	-1.96878[C]	2.7442112(10)[C]
		-2.01104[B]	2.4897656(10)[B]
$7g_{7/2}$ - $9f_{7/2}$	1.07(1)[A]	-3.30214[A]	3.62466(9)[A]
	1.0715925(1)[B]	-2.70536[C]	1.4309659(10)[C]
		-2.87087[B]	9.7752369(9)[B]
$7g_{9/2}$ - $8f_{7/2}$	1.84(1)[A]	-0.42778[A]	9.24475(11)[A]
	1.8384593(1)[B]	-0.35325[C]	1.0936841(12)[C]
		-0.39157[B]	1.0013185(12)[B]

$7g_{9/2}$ - $9f_{7/2}$	1.08(1)[A]	-1.45677[A]	2.48983(11)[A]
	1.0826264(1)[B]	-1.09934[C]	5.6592621(11)[C]
		-1.24614[B]	4.0360259(11)[B]
$8s_{1/2}$ - $8p_{1/2}$	2.31(3)[A]	-1.11537[A]	4.79400(7)[A]
	4.1707316(3)[B]	-4.45203[C]	6.7710191(3)[C]
		-1.43857[B]	6.9842222(6)[B]
$8d_{3/2}$ - $8p_{3/2}$	6.45(3)[A]	-1.98181[A]	4.18607(5)[A]
$8d_{3/2}$ - $8f_{3/2}$	5.3251531(4)[B]	-0.89685[C]	7.4571378(4)[C]
		-2.92246[B]	7.0299990(2)[B]
$8d_{5/2}$ - $8f_{5/2}$	1.57(4)[A]	-2.59845[A]	1.14084(4)[A]
	2.3871407(5)[B]	-0.28288[C]	1.0170812(4)[C]
		-3.793[B]	3.1421825[B]
$8f_{5/2}$ - $8g_{7/2}$	1.20(3)[A]	-0.23423[A]	3.39068(8)[A]
	9.2489920(2)[B]	0.063269[C]	1.1275445(9)[C]
		-0.12832[B]	7.2534160(8)[B]
$8f_{5/2}$ - $9g_{7/2}$	2.58(1)[A]	0.730162[A]	6.74768(12)[A]
	2.5604265(1)[B]	0.723649[C]	6.7309679(12)[C]
		0.734557[B]	6.9021684(12)[B]
$8f_{7/2}$ - $8g_{7/2}$	2.2992356(5)[B]	-0.35611[C]	6.9466725(3)[C]
		-3.96114[B]	1.7248484[B]
$8f_{7/2}$ - $9g_{7/2}$	2.64(1)[A]	-0.66024[A]	2.62541(11)[A]

		2.6336273(1)[B]	-0.66141[C]	2.6214026(11)[C]
			-0.64938[B]	2.6950609(11)[B]
$8f_{7/2}$	- $8g_{9/2}$	1.83(3)[A]	-0.30773[A]	9.81990(7)[A]
		1.5801326(3)[B]	0.061199[C]	3.0757795(8)[C]
			-0.24722[B]	1.5119492(8)[B]
$8f_{7/2}$	- $9g_{9/2}$	2.61(1)[A]	0.867436[A]	7.21744(12)[A]
		2.6029962(1)[B]	0.85645[C]	7.0736905(12)[C]
			0.867878[B]	7.2622985(12)[B]
$8g_{7/2}$	- $9f_{5/2}$	2.67(1)[A]	-0.44747[A]	5.56780(11)[A]
		2.6868414(1)[B]	-0.2354[C]	8.9558169(11)[C]
			-0.32838[B]	7.2297485(11)[B]
$8g_{7/2}$	- $8f_{7/2}$	3.43(4)[A]	-3.12915[A]	5.25395(2)[A]
		2.2992356(5)[B]	-0.35611[C]	6.9466725(3)[C]
			-3.96114[B]	1.7248484[B]
$8g_{7/2}$	- $9f_{7/2}$	2.63(1)[A]	-1.97565[A]	1.27324(10)[A]
		2.6330379(1)[B]	-1.77289[C]	2.0288649(10)[C]
			-1.8855[B]	1.5654348(10)[B]
$8g_{9/2}$	$9f_{7/2}$	2.67(1)[A]	-0.31587[A]	5.64183(11)[A]
		2.6779687(1)[B]	-0.16373[C]	7.9747215(11)[C]
			-0.26341[B]	6.3392408(11)[B]

$9s_{1/2}$	- $9p_{1/2}$	4.22(3)[A]	-1.13248[A]	1.38177(7)[A]
		6.3510747(3)[B]	-1.72503[C]	1.5573577(6)[C]
			-1.39244[B]	3.3495043(6)[B]
$9p_{3/2}$	- $9d_{3/2}$	1.10(4)[A]	-1.97116[A]	1.47981(5)[A]
		8.7079821(4)[B]	-0.11344[C]	1.6935854(5)[C]
			-2.90711[B]	2.7235449(2)[B]
$9d_{5/2}$	- $9f_{5/2}$	2.48(4)[A]	-2.55247[A]	5.08560(3)[A]
		2.5418043(5)[B]	0.404348[C]	4.3657174(4)[C]
			-3.58288[B]	4.4959885[B]
$9f_{5/2}$	$9g_{7/2}$	1.94(3)[A]	-0.18815[A]	1.44079(8)[A]
		1.3221026(3)[B]	0.3698[C]	1.1176955(9)[C]
			-0.0316[B]	4.4353195(8)[B]
$9f_{7/2}$	$9g_{9/2}$	2.86(3)[A]	-0.25189[A]	4.56584(7)[A]
		2.2590058(3)[B]	0.473375[C]	3.8876168(8)[C]
			-0.15058[B]	9.2413090(7)[B]
$9g_{7/2}$	$9f_{7/2}$	4.97(4)[A]	-3.03505[A]	3.11362(2)[A]
		2.4101420(5)[B]	0.435448[C]	3.9121586(4)[C]
			-3.72854[B]	2.6818389[B]

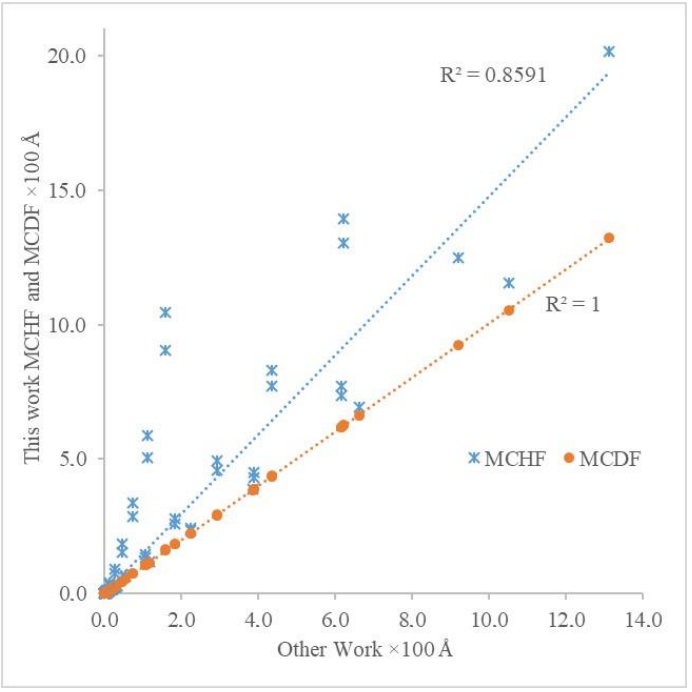

Figure 1 The wavelengths comparison of E1 transitions for No^{101+} between obtained MCHF and MCDF results in present work and other work [6].

CONCLUSION

The paper has intended to bring the wavelength, weighted oscillator strength, and transition probabilities in high accuracy for E1, E2 and M1 transitions between *nl* (*n*=1-9, *l*=0-4) levels of No^{101+}. The investigation has been performed using MCHF approximation and MCDF method. This study has been actually carried out as part of a extensive investigation about one, two and three electron actinide ions with $89 \leq Z \leq 103$. The Breit-Pauli, transverse photon and QED contributions have considered for high precision in the calculations. It is a hope that the present investigation will spearhead to theoretical or experimental examinations and also in the field of technology in future for hydrogen like nobelium No^{101+}.

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