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Characterization of hot dense plasma with plasma parameters

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ABSTRACT

Characterization of hot dense plasma (HDP) with its parameters temperature, electron density, skin depth, plasma frequency is demonstrated in this work. The dependence of HDP parameters on temperature and electron density is discussed. The ratio of the intensities of spectral lines within HDP is calculated as a function of electron temperature. The condition of weakly coupled for HDP is verified by calculating coupling constant. Additionally, atomic data such as transition wavelength, excitation energies, line strength, etc. are obtained for Be-like ions on the basis of MCDHF method. In atomic data calculations configuration interaction and relativistic effects QED and Breit corrections are newly included for HDP characterization and this is first result of HDP parameters from extreme ultraviolet (EUV) radiations.

1. Introduction

In recent years, the description and study of hot dense plasma parameters is a topic of effectual theoretical and experimental analysis and exploration (Kodanova et al., 2017). On account of the significance of hot dense plasma in inertial confinement fusion (ICF), it has been produced by employing different experiments such as heavy ion driven fusion, magnetized Z-pinch etc. (Hoffmann et al., 2005; Yu. Sharkov et al., 2016; Kawata et al., 2016; Hurricane et al., 2014; Gomez et al., 2014 in last few years. The high energy density plasma (HDEP) or hot dense plasma (HDP) is characterized by the matter of temperature in keV range with solid state density (Attwood and Sakdinawat, 2017). The matter with these basic parameters in this range is of interest in diversified areas of physics such as material science, planetary physics, astrophysics etc. Further, characterization and modeling of plasmas helps in understanding and analyzing the various atomic processes responsible for plasmas and occur in plasmas. In past few decades, high temperature plasmas and their applications have directly affected our daily lives by doing advancements and developments in the light sources, laser surgeries, cancer treatments, computer chips etc. (Caillard et al., 2007; Hatakeyama et al., 2014; Kakiuchi et al., 2014. Therefore, in this paper, we have discussed the characterization of HDP with its parameters.

There are some theoretical and experimental researches in the literature on highly ionized Be-like ions which have been performed by implementing several types of technologies (Malyshev et al., 2014; Majumdar and Das, 2000; Safronova et al., 1996, 1999; Verdebout. et al., 2014; Safronova, 2000; Marques et al., 2012, 1993; Bhatia et al., 1986; Sampson et al., 1981; Natrajan and Natrajan, 2007; Argaman et al., 2013; Cheng et al., 2008; Xi et al., 1993; Tunnel and Bhalla, 1979; Sims and Hagstrom, 2014; Safronova and Shlyaptseva, 1996). The importance, applications and prominence of Be-like ions can also be revealed from the fact that these ions are topic of current research and interest for researchers till now because four electron system is the simplest system in which intrashell and intershell interactions are significant while two and three electron systems separately show intrashell and intershell interactions. Fritzsche et al. (2015) proved that lifetime of 2s2p ^3P_o state of Be-like ions is longest than all medium and heavy elements by using relativistic second-order perturbation theory, which makes them potential candidate for plasma physics and astrophysics. Malyshev et al. (2015) have reported ionization energies of Be-like ions with atomic number ranges from 16 to 96 by using two time green function (TTGF) method for the fabrication of QED perturbation series. Wang et al. (2015) have calculated energy levels and radiative data for Be-like ions among 116 levels by applying combined configuration interaction and many-body perturbation method. Sang et al. (2016) have presented energies, radiative and non-radiative data for the core-excited states of $1s2p^3$ for Be-like ions with nuclear charge from 8 to 54 by implementing fully relativistic multi-configuration Dirac-Fock (MCDF) method. (Kilin, 2016) has predicted error in the order of location of energy levels for Li and Be-like ions for nuclear charge greater than 50 by analysis of total and one electron energies computed by making use of Hartree-Fock-Dirac (HFD) approximation. Further, the transitions from excited states to ground state of Be-like ions is prerequisite from astrophysical point of view because these ions have been identified in plenteous amount in various astronomical bodies such as Sun, planetary

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Table 1
Energy levels (in cm^{-1}) for Be-like Zn for lowest 45 fine structure levels. a-NIST, b-Ref. Bhatia et al. (1986), c-Ref. Wang et al. (2015).

S. no	Configuration	Term	J	Parity	GRASP2K				FAC	others
					n = 4	n = 5	n = 6	n = 7		
1	$2s^2$	^1S	0	+	0.00	0.00	0.00	0.00	0.00	0.00
2	2s2p	^3P	0	–	409779.27	409333.07	408723.83	409705.26	409335.56	409450[b]
3	2s2p	^3P	1	–	460019.44	460102.26	460077.96	459533.20	459422.11	459640[a] 459443[b]
4	2s2p	^3P	2	–	640260.25	638859.13	638606.04	638166.80	639814.87	640470[a] 640315[b]
5	2s2p	^1P	1	–	961789.46	960672.85	959886.69	957370.86	960504.07	954808[a] 955349[b]
6	$2p^2$	^3P	0	+	1147575.11	1146406.30	1145177.24	1144788.42	1145428.05	1144439[b]
7	$2p^2$	^3P	1	+	1298244.00	1297611.66	1297444.33	1296126.54	1296876.99	1296741[b]
8	$2p^2$	^3P	2	+	1360747.97	1356896.32	1356839.64	1355408.34	1358910.76	1355187[b]
9	$2p^2$	^1D	2	+	1585668.10	1581677.03	1581553.70	1579847.32	1583488.48	1583476[b]
10	$2p^2$	^1S	0	+	1835486.87	1832159.91	1829558.84	1828490.99	1835070.30	1826481[b]
11	2s3s	^3S	1	+	12168171.53	12168477.23	12168578.83	12168047.67	12175039.66	12132000[a] 12201547[b] 12171545[c]
12	2s3s	^1S	0	+	12251233.01	12251045.96	12250937.59	12250929.35	12260166.43	12296928[b]
13	2s3p	^3P	1	–	12367008.13	12366545.66	12366025.97	12366889.00	12375959.84	12368000[a] 12402866[b]
14	2s3p	^3P	0	–	12367387.13	12367330.07	12367340.83	12367319.95	12376200.03	12395484[b]
15	2s3p	^1P	1	–	12428456.53	12428424.26	12428454.20	12427913.22	12436868.62	12429500[a] 12483758[b]
16	2s3p	^3P	2	–	12433102.13	12433611.47	12431400.24	12431052.44	12441861.68	12457824[b]
17	2s3d	^3D	1	+	12535366.31	12535083.77	12534655.95	12533892.70	12541988.98	12525000[a] 12564579[b]
18	2s3d	^3D	2	+	12543495.24	12539627.35	12539755.76	12538952.91	12550072.43	12571651[b]
19	2s3d	^3D	3	+	12555640.20	12555830.16	12552242.31	12551682.63	12564375.45	12585065[b]
20	2s3d	^1D	2	+	12631411.00	12625661.57	12625468.08	12623677.98	12637746.78	12615000[a] 12662487[b] 12628457[c]
21	2p3s	^3P	0	–	12686725.54	12686783.62	12687261.63	12687538.54	12697916.92	
22	2p3s	^3P	1	–	12711754.15	12711621.82	12711609.97	12710929.22	12723085.68	
23	2p3p	^3D	1	+	12818902.41	12818907.59	12818835.24	12817853.31	12828643.20	12817000[a]
24	2p3s	^3P	2	–	12920254.10	12920981.56	12918797.10	12918457.55	12930549.20	
25	2p3p	^3D	2	+	12927233.71	12924062.38	12924170.57	12923273.90	12938633.53	12928496[c]
26	2p3p	^3P	1	+	12927707.77	12926908.07	12926813.00	12925769.32	12938713.94	
27	2p3p	^3P	0	+	12931748.26	12930784.19	12929823.27	12929640.43	12948176.19	
28	2p3s	^1P	1	–	12972721.33	12971994.98	12971833.63	12970550.85	12984237.22	
29	2p3d	^3F	2	–	12989527.36	12989915.34	12987774.58	12987375.21	13000414.92	
30	2p3d	^3F	3	–	13051934.42	13045433.88	13045447.85	13044982.92	13065656.35	
31	2p3d	^3P	2	–	13065943.29	13065995.00	13063849.36	13063354.67	13076476.19	
32	2p3d	^3D	1	–	13080448.27	13079456.14	13079318.27	13078633.25	13090468.69	
33	2p3p	^3P	1	+	13098731.25	13098268.66	13098170.10	13097126.97	13111380.70	
34	2p3p	^3P	2	+	13122389.18	13118511.82	13118531.76	13117340.41	13134285.22	13104494[c]
35	2p3p	^3D	3	+	13123354.57	13125873.59	13119964.26	13119605.63	13136366.05	
36	2p3p	^3S	1	+	13137873.12	13137192.42	13137085.55	13136127.96	13147112.33	13139087[c]
37	2p3p	^1D	2	+	13221099.51	13216948.32	13216896.01	13215511.91	13236017.49	13220226[c]
38	2p3d	^1D	2	–	13247156.67	13247835.21	13245518.40	13245148.01	13252423.44	
39	2p3d	^3D	3	–	13273318.32	13266909.81	13267123.02	13266642.08	13257030.56	
40	2p3d	^3P	1	–	13301207.20	13300578.99	13300558.44	13299944.22	13286218.86	
41	2p3d	^3P	2	–	13303850.71	13304202.28	13301825.16	13301339.26	13310817.23	
42	2p3d	^3P	0	–	13305454.96	13304568.55	13304582.40	13304968.22	13313489.99	
43	2p3p	^1S	0	+	13313393.32	13310548.33	13308570.30	13308171.57	13315412.81	
44	2p3d	^1F	3	–	13369748.65	13361870.54	13361382.43	13359811.27	13328308.48	
45	2p3d	^1P	1	–	13389221.07	13386703.87	13386194.52	13384832.24	13380954.28	

nebulae (PN) and quasi-stellar objects (Kholtygin, 1998). The inclusion of core-excited states of Be-like ions is necessary for better understanding, analysis, investigation and diagnosis of ion-atom/electron collision processes and plasmas (Biémont et al., 2000; Smith et al., 1995). Therefore, in the present work, we have studied Be-like ions by including core-excited states in our calculations upto n = 7 in a systematic manner.

Further, a considerable attention has been given to highly charged ions (HCI) due to their applications in investigation and inspection of various types of plasmas and their modeling. The spectral lines and the atomic spectra of these ions are also useful in the determination of plasma parameters such as electron density, plasma temperature, skin depth, etc. (Masoudnia and Bleiner, 2015; Salik et al., 2013; Esaulov et al., 2012. The atomic parameters also decides the whether the plasma is cool or hot dense plasma. For these ions, the contribution of quantum electrodymanics (QED) to energy levels increases which adversely affects the analysis of plasma diagnostics for the accurate and precise instrumentation of nuclear physics demonstration and description for HCI. As the electron temperature within the range 5–10 keV have already obtained in large Tokamaks such as Tokamak Fusion Test Reactor (TFTR) and Joint European Torus and experiments are going on to achieve the temperature upto few MeV, the study of HCI is very important. The wavelengths of most of the spectral lines of HCI lies in EUV and X-ray regions and can be used in the determination of plasma parameters. In these atomic data calculations configuration interaction and relativistic effects QED and Breit corrections are newly included for