Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 54 (2014) 1190–1194

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

The OIV 1407.3 Å /1401.1 Å emission-line ratio in a plasma

Nabil Ben Nessib [a], Norah Alonizan [a], Rabia Qindeel [a], Sylvie Sahal-Bréchot [b], Milan S. Dimitrijević [b,c,*]

[a] Department of Physics and Astronomy, College of Science, King Saud University, PO Box 2455, Riyadh 11451, Saudi Arabia
[b] Laboratoire d'Étude du Rayonnement et de la Matière en Astrophysique, Observatoire de Paris, UMR CNRS 8112, UPMC, 5 Place Jules Janssen, 92195 Meudon Cedex, France
[c] Astronomical Observatory, Volgina 7, 11060 Belgrade, Serbia

Available online 30 October 2013

Abstract

Line ratio of O IV 1407.3 Å/1401.1 Å is calculated using mostly our own atomic and collisional data.

Energy levels and oscillator strengths needed for this calculation have been calculated using a Hartree–Fock relativistic (HFR) approach. The electron collision strengths introduced in the statistic equilibrium equations are fitted by polynomials for different energies. Comparison has also been made with available theoretical results.

The provided line ratio has been obtained for a set of electron densities from 10^8 cm^{-3} to 10^{13} cm^{-3} and for a fixed temperature of 50,000 K.

Keywords: Atomic data; Atomic processes; Line ratio

1. Introduction

Triply charged oxygen ion (O IV) belongs to the boron isoelectronic sequence, its ground state configuration is $2s^2$ $2p$ $^2P^o$. The boron like ions are widely observed in a variety of astrophysical plasmas. Many researchers have been done a lot of calculations for many parameters of O IV due to its importance in astrophysical plasma. Aggarwal and Keenan (2008) calculated energy levels, radiative rates (A values) and excitation rates or equivalently the effective collision strengths (gamma) which are obtained from the electron impact collision strength (Ω). Feldman et al. (1997) presented a solar coronal spectrum recorded by the extreme UV spectrometer SUMER on the Solar and Heliospheric Observatory. The detected O IV lines covered the wavelength range 500–1610 Å. The studied range contains the $2s^2$ $2p$ $^2P^o$–$2s$ $2p^2$ ^4P intercombination transitions. Harper et al. (1999) obtained a high signal-to-noise ratio spectra of RR Tel at medium resolution with the Goddard High-Resolution Spectrograph (GHRS) on the Hubble Space Telescope (HST) to test available atomic data for the intercombination transitions in O IV (multiplet: UV 0.01). Blair et al. (1991) observed the far-ultraviolet spectrum of the Cygnus Loop supernova remnant using the Hopkins Ultraviolet Telescope aboard the Astro-1 space shuttle. Similarly, Redfield et al. (2002) have been detected lines of O IV in late-type stars within the wavelength range of 910-1180 Å. Sturm et al. (2002) studied emission lines of O IV in IR range from active galactic nuclei and (Pagano et al., 2000) observed them in the solar transition region. Keenan et al. (2009) generated theoretical UV and extreme-UV emission line ratio for O IV and presented their strong versatility for diagnostics of electron temperature and electron density for astrophysical plasmas. Extreme-ultraviolet lines emission arising from radiative transition probabilities and electron collision cross-sections

* Corresponding author at: Astronomical Observatory, Volgina 7, 11060 Belgrade, Serbia. Tel.: +381 642978021; fax: +381 2419553.

E-mail addresses: nbennessib@ksu.edu.sa (N. Ben Nessib), nalonizan@ksu.edu.sa (N. Alonizan), rqindeel@ksu.edu.sa (R. Qindeel), Sylvie.Sahal-Brechot@obspm.fr (S. Sahal-Bréchot), mdimitrijevic@aob.bg.ac.rs (M.S. Dimitrijević).

0273-1177/\$36.00
http://dx.doi.org/10.1016/j.asr.2013.10.021

in B-like ions were calculated by Flower and Nussbaumer (1975).

Using semiclassical approach, Dimitrijević and Sahal-Bréchot (1995) calculated electron-, proton-, and He III-impact line widths and shifts for 5 multiplets of O IV. The widths, shifts and fitting coefficients data are in the database STARK-B (Sahal-Bréchot et al., 2012).

Recently, Olluri et al. (2013) studied the non-equilibrium ionization effects on the line ratio of O IV.

In this work, we will study the influence of the atomic data on the emission line ratio I(1407.1 Å)/I(1401.1 Å).

2. Atomic data

In this work, energy levels and oscillator strengths are calculated with the Hartree–Fock relativistic (HFR) approach using Cowan code (Cowan, 1981) and an atomic model including the 13-configurations: $2s^2\,2p$, $2s\,2p^2$, $2p^3$, $2s^2\,3s$, $2s^2\,3p$, $2s^2\,3d$, $2s^2\,4s$, $2s^2\,4p$, $2s^2\,4d$, $2s^2\,4f$, $2s\,2p\,3s$, $2s\,2p\,3p$ and $2s\,2p\,3d$.

The obtained energy level data are compared in Table 1 with those of NIST (Kramida et al., 2012), GRASP2 (Aggarwal and Keenan, 2008) (using 219 levels) and MCHF (Tayal, 2006).

The spontaneous emission radiative rate (the so-called Einstein's A-coefficient), A_{ji} is related with the absorption oscillator strength f_{ij} for the transition $i \rightarrow j$ by the standard relation:

$$A_{ji}(\mathrm{a.u}) = \frac{1}{2}\alpha^3 \frac{g_i}{g_j} E_{ji}^2 f_{ij} \tag{1}$$

where E_{ji} is the transition energy between states i and j in Rydberg units, α is the fine structure constant and g_i and g_j are the statistical weight factors of the initial and final states respectively.

The transition probability in s^{-1} is then:

$$A_{ji}(\mathrm{s}^{-1}) = \frac{A_{ji}(\mathrm{a.u})}{\tau_0} \tag{2}$$

with $\tau_0 = 2.4191 \times 10^{-17}$ is the atomic unit of time.

In Table 2, we have compared our values of $\log(g_i f_{ij})$ and transition probability $A_{ji}(\mathrm{s}^{-1})$ with the values taken from NIST database (Kramida et al., 2012) and results from Galavís et al. (1998), Flower and Nussbaumer (1975) and Tayal (2006). Observed wavelengths are from Bromander (1969).

3. Collisional data

The excitation rate coefficient in $\mathrm{cm^3 s^{-1}}$ can be expressed by the effective collision strength as:

$$C_{ij} = \frac{8.629 \times 10^{-6}}{g_i T^{1/2}} \gamma_{ij}(T) \exp\left(-\frac{E_j - E_i}{kT}\right) \tag{3}$$

where $\gamma_{ij}(T)$ is the effective collision strength related to the collision strength Ω_{ij} by:

$$\gamma_{ij}(T) = \int_0^\infty \Omega_{ij} \exp\left(-\frac{E_j}{kT}\right) d\left(\frac{E_j}{kT}\right) \tag{4}$$

The excitation rate coefficient C_{ij} can also be written as a function of the cross-section:

$$C_{ij} = N_e \int_{v_0}^\infty v\sigma_{ij}(v) f(v) dv \tag{5}$$

where v_0 is the threshold velocity and $f(v)$ is the Maxwellian velocity distribution function for electrons.

The semiclassical cross-section $\sigma_{ij}(v)$ can be expressed by an integral over the impact parameter ρ of the transition probability $P_{ij}(\rho, v)$ as

$$\sigma_{ij}(v) = \frac{1}{2}\pi R_1^2 + \int_{R_1}^{R_D} 2\pi\rho d\rho P_{ij}(\rho, v). \tag{6}$$

R_D is the Debye radius and R_1 is the minimum cut-off radius (see Sahal-Bréchot, 1969, and Seaton, 1962 for neutrals).

4. Line ratio

In a steady state regime, we can write that:

$$\begin{aligned} \frac{dN_i}{dt} &= \sum_{j\neq i, j>i} N_j (C_{ji} + A_{ji}) + \sum_{j\neq i, j<i} N_j C_{ji} \\ &\quad - N_i \left[\sum_{j\neq i,\ i<j} C_{ij} + \sum_{j\neq i,\ i>j} (C_{ij} + A_{ij}) \right] = 0, \end{aligned} \tag{7}$$

where N_i is the number of ions per unit of volume for the energy level i, C_{ij} is the electron collisional rate for transferring ions from level i to level j, and C_{ji} is the collisional rate for transferring ions from level j to level i. In fact, since the local incident radiation is very weak, absorption and induced emission rates are completely negligible compared to collisional rates. So, for transferring ions from level i to level j (or from level j to level i) by radiative processes, only spontaneous emission rates A_{ij} (or A_{ji}) are to be taken into account.

Solving the above set of equations, we obtain the relative populations N_i/N_j for any two levels. The normalization is obtained by the constraint $\sum_i N_i = N_{ion}$, where N_{ion} is the ion density per unit volume.

The local emissivity in the line studied (in units of energy, per unit of volume, per unit of time, and per steradian) for a transition from state j to state i is given by:

$$\varepsilon_{ji} = \frac{h\nu}{4\pi} A_{ji} N_j \tag{8}$$

where h is the Planck constant, and ν the frequency of the transition.

In "mode 1" of Dufton (1977), the observed intensity ratio of two lines is equal to the relevant line emissivity ratio. This is currently assumed in UV coronal studies, and justified when the two lines are formed in the same region of the plasma, and in addition if the emissivities vary slowly in the regions of emission. As Keenan et al. (2009),