Cesium satellite band at 875.2 nm stemming from the Cs$_2$ $0^+_g(6p\ ^2P_{1/2} + 6s\ ^2S_{1/2})$ state

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Abstract. We measured a very distinct satellite band at 875.2 nm between two resonance lines of cesium. Spectral simulation using Spies and Meyer [1] ab initio potential curves and an appropriate transition dipole moment function was compared with experimental profile. Implications of the investigated satellite band at 875.2 nm in the field of ultracold cesium atom collisions are discussed with a special emphasize to new possibilities of the photoassociation of two ground state atoms leading to the formation of ultracold intermediate long-range molecules.

PACS. 33.70.Jg Line and band widths, shapes, and shifts – 34.20.Cf Interatomic potentials and forces

1 Introduction

The self-broadening of the first cesium resonance lines was widely investigated experimentally and theoretically [2–5]. The results of resonance broadening experiments are mostly used for testing the different theoretical models, for the determination of the accuracy of the calculated ab initio potential curves and for the diagnostics of high-pressure lamps.

Interaction energies, i.e. potential energy curves of two Cs atoms can be classified as in potassium case [6] as: short range (5 Bohr $\leq R \leq 16$ Bohr), intermediate range [7] (16 Bohr $\leq R \leq 30$ Bohr) and long-range (R $\geq 30$ Bohr). During the past decade the accurate determinations of the molecular intermediate and long-range potentials played crucial role in the interpretation of many new physical phenomena associated with the cold atom collisions and ultracold molecules. In this paper we are dealing with the Cs$_2$ intermediate molecular states stemming from 6 $^2S_{1/2} + 6^2P_{1/2}$ and 6 $^2S_{1/2} + 6^2P_{3/2}$ asymptotes.

The first discussion on the origin of these satellite bands in the far quasistatic wings of the Cs resonance line was reported in reference [8]. Quite recently Veža et al. [9] reported on the blue satellite bands of cesium 852.1 nm line at 817 nm, 827 nm and 835 nm as stemming from the maxima in difference potential curves of the 1(3)$^3\Sigma_u^+(1_u, 0_u^-) \rightarrow 1^3\Pi_g(2_g, 1_g, 0_g^+, 0_g^-)$ electronic transitions (Fig. 1a). Here, we are using Hund’s case (a) and (c) (in brackets) designations [10]. Upper electronic $2_g, 1_g, 0_g^+$ and $0_g^-$ states have the same 6 $^2S_{1/2} + 6^2P_{3/2}$ asymptote. The authors devoted a special discussion to the $1_u \rightarrow 0_g^-$ transition, since the corresponding difference potential curve has two maxima and one minimum at about 17 Bohr, which produces interesting features in the observed absorption spectrum (cusp satellite bands).

In Figure 1a Cs$_2$ potential curves [1] needed for the interpretation of the 875.2 nm band are shown. Cs$_2$ 1 $^3\Pi_g$ and 2 $^1\Sigma_g^+$ potential curves calculated without the inclusion of the spin-orbit interaction and classified as the Hund’s case (a), are represented by dashed lines. Full lines represent $0_g^+$ adiabatic potential curves calculated with inclusion of spin-orbit interaction and classified according to the notation of the Hund’s case (c). The spin-orbit interaction removes the degeneracy at the crossing point and because of the well-known Neumann-Wigner theorem [11] an avoided crossing appears between the two $0_g^+$ potential curves at the internuclear distance around 21 Bohr. This avoided crossing produces extrema in the potential curves of both $0_g^+$ states. The maximum in the $0_g^+$ potential curve stemming from the 6s $^2S_{1/2} + 6p^2P_{1/2}$ asymptote is responsible for the formation of the 875.2 nm satellite band, treated in this paper experimentally and theoretically. In what follows this state will be denoted by $0_g^+$ (6s $^2S_{1/2} + 6p\ ^2P_{1/2}$).

It is interesting to note that the maximum in $0_g^+$ (6 $^2S_{1/2} + 6^2P_{1/2}$) potential curve is essentially a potential barrier that splits bound states at shorter distances and continuum states at larger distances of the interacting cesium atoms (see Fig. 1a). In order to obtain relevant molecular electronic dipole transition moments and

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corresponding molecular oscillator strengths, a semi-empirical “atoms in molecules” scheme developed by Cohen and Schneider [12] was used. In Figure 1b the molecular oscillator strengths \( f \) as a function of the internuclear distance \( R \) for the 1-a and 2-a transitions (shown by arrows in (a)). For the sake of simplicity the lowest triplet potential \( a \ ^3Σ_u^- \) is denoted with \( a \).

2 Experiment

We performed absorption measurements with the cesium all-sapphire cell (ASC) [13] and the emission measurements with the high pressure Cs lamp (OSRAM, Germany).

The ASC is cylindrical in shape with an internal diameter of 10 mm, wall thickness of 3 mm and length of 160 mm. Inside the ASC is a tablet of powders that provides 0.6 mg of pure cesium. The temperature was measured by a thermocouple positioned at the middle point of the ASC. The detailed description of the cesium ASC and the experimental setup for the absorption measurements was given in previous papers [14–16]. The continuous light from a halogen lamp irradiated the ASC. The light passing through the absorption cell was spectrally analyzed using a Jobin Yvon THR 1.5 m grating spectrometer equipped with a holographic grating (1200 grooves/mm) and detected with the Hamamatsu S1336-4BQ silicon photodiode. The photodiode output signal was fed into a lock-in amplifier (Stanford Research SR510) and stored in a personal computer.

High-pressure cesium vapor lamp (OSRAM) used for the emission measurements was operated at the power of 80 W and 50 Hz AC. The burner of the lamp is a cylindrical tube made of the translucent alumina and filled with Cs and Xe [17]. In order to obtain time-resolved spectra from the sinusoidally driven plasma, the Boxcar Averager (Model 162 and 164, Princeton Applied Research) was used for processing the signal from the photodiode. The emission spectra at the current maximum point and at the current reversal point were taken.

2.1 Emission spectra

Emission spectra from the lamp are rather complex because of the thermal nonuniformity of the plasma column inside the burner. The central part of the plasma column is hotter then the outer part, so the emitted light from the core is partially absorbed in the outer layers of the column. At the current maximum point the plasma temperature and the electron density attain the largest values and therefore excited levels in Cs atoms are substantially populated even in outer layers of the burner. At the current reversal point, cesium plasma becomes much colder (the electron temperature is at minimum value).

The emission spectrum from the lamp taken at the current maximum is shown in Figure 2a. Atomic lines belonging to the sharp and diffuse series are easily identified on the elevated thermal background mainly consisting of the very far resonance line wings emission. There is huge absorption at positions of D1 and D2 resonance lines (894.3 and 852.1 nm). Due to the large population of the first excited state in cesium atom, \( 6 \ ^2P_1/2,3/2 \); some of the lines ending at resonance levels are self-reversed. Atomic lines coming from \( 4 \ ^2F_5/2 \rightarrow 5 \ ^2D_3/2 (1002.4 \text{ nm}) \), \( 4 \ ^2F_5/2 \rightarrow 5 \ ^2D_3/2 \), and \( 4 \ ^2F_7/2 \rightarrow 5 \ ^2D_3/2 (1012.3 \text{ nm}) \) transitions are also self-reversed. The 875.2 nm satellite overlaps with the atomic line at 876.1 nm that comes...