Multichannel tunneling in the Cs_2 0_g^- photoassociation spectrum and formation of ultracold molecules

M. Vatasescu [1,2], C. Amiot[1], O. Dulieu [1], V. Kokoouline [1,3], F. Masnou-Seeuws[1]
C. Drag[1], D. Comparat[1] and P. Pillet[1]

[1] *Laboratoire Aimé Cotton,Campus d'Orsay, 91405 Orsay, France*
E-mail: francoise.masnou@lac.u-psud.fr, Website: http://www.lac.u-psud.fr
[2] *Institute for Space Sciences, Bucarest-Magurele, Romania*
[3] *The Institute of Physics, Saint-Petersburg State University,Saint-Petersburg, Russia*

During the past decade, laser cooling and trapping of atoms have lead to fascinating experimental achievements. In contrast, direct laser cooling of molecules is very difficult due to the lack of a close two-level optical pumping scheme for recycling population. In a cold atom trap, photoassociation (PA) [1] is making cold molecules in an excited electronic state, mostly decaying by spontaneous emission back into a pair of free atoms. The formation of ground state ultracold molecules has been observed for the first time by PA of two cold cesium atoms into rovibrational levels of the Cs_2 $0_g^-(6s + 6p_{3/2})$ state [2]. Due to the double well structure of the excited potential curve (Fig. 1), decay towards rovibrational levels of the lowest $a^3\Sigma_u^+$ triplet state provides an efficient process for formation of ultracold molecules, detected through photoionization into Cs_2^+ ions as a function of detuning. From the PA spectrum the molecular potential curve in the region of the external well has been determined by an RKR-NDE approach [3], and is in good agreement with theoretical calculations [4, 5]. Also present in the experimental spectrum are two giant lines (Fig. 2), corresponding to binding energies E_1 =-2.14 cm^{-1}, E_2 =-6.15 cm^{-1} relative to the $6s + 6p_{3/2}$ dissociation limit. They display a well-resolved rotational structure (B_v^1= 137 MHz and B_v^2= 189 MHz) (Fig. 2), typical of vibrational motion in the region of the inner well. We show that these two giant structures, which are signatures of a *high molecule production rate of ultracold molecules*, can be interpreted as due to the cooperative effect of *tunneling* towards the inner well of the $0_g^-(6s + 6p_{3/2})$ curve, and *dynamical coupling*, in the inner region, with levels of the $0_g^-(6s + 5d_{3/2})$ excited state. Calculations are performed using the Mapped Fourier Grid Representation method [6]. Good agreement is obtained between theory and experiment, yielding information on the barrier between the two wells. Moreover, we predict that the ultracold molecules are formed in low vibrational states.

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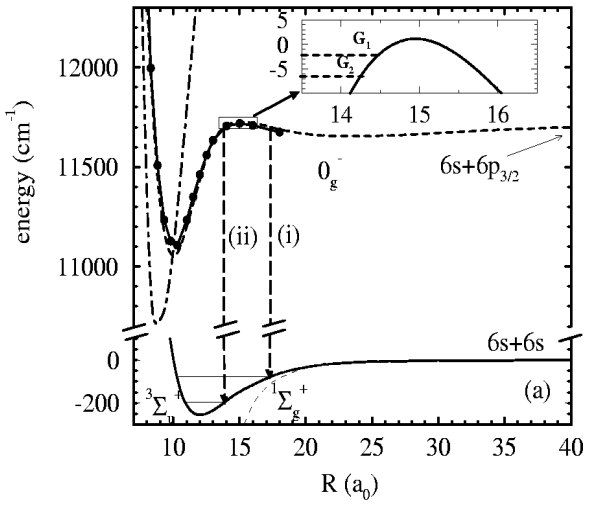

Figure 1: Cs_2 potential curves (extracted from ref. [4, 5]) for the triplet and singlet lowest electronic states (thin solid and broken lines) and for the excited electronic state 0_g^- (6s+6p $^2P_{3/2}$) ($V_1(R)$, broken line or $V_1^d(R)$ solid lines).(i) and (ii) lines schematize the spontaneous emission from the excited state.

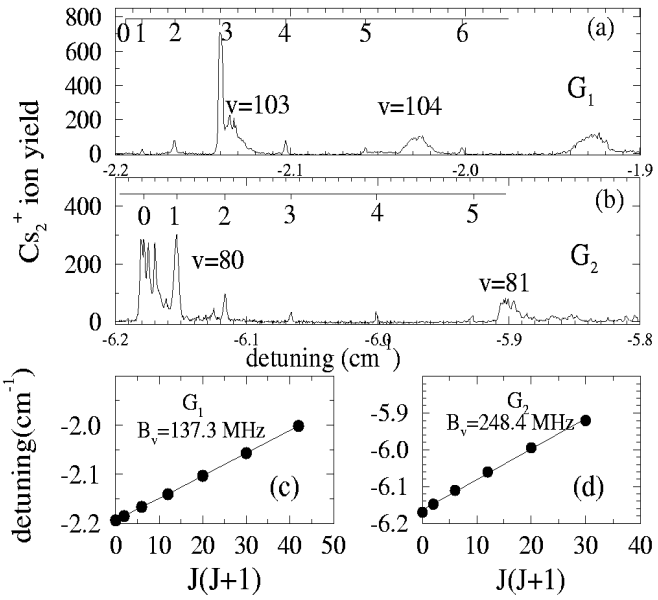

Figure 2: (a) Details of the structure G_1 observed at detuning E_{v1}=-2.14cm^{-1} in the PA spectrum, showing the J labelling of the rotational levels. Lines assigned to the $v_e = 103, 104, 105$ levels of the 0_g^- external well are also indicated, and it is clear that their unresolved rotational structure correspond to smaller rotational constants. (c) Variation of the binding energy $E_{vJ} = B_v J(J+1)$ of the rotational levels identified in the G_1 structure. (b) and (d): same as (a) and (c) respectively for G_2 structure.