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Dominant wing spectroscopy of energy pooling collisions near the boundary layer involving thermal caesium vapour*

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We have observed the dominant wing spectroscopy of energy pooling collision near the boundary layer involving Cs atoms under the condition of moderate-to-high optical depths at line-centre. It appears from our experimental investigations that the energy-pooling fluorescence presents about 16 spectral lines, and all the lines can be assigned to the Cs atomic transitions. We find that all lines of the energy-pooling retrofluorescence from the heated Cs atomic vapour cell show two-peak profiles. In addition, its pumping power linear dependence in the energy pooling process has been measured and analysed.

Keywords: collision, energy pooling, fluorescence
PACC: 3250F, 3450D

1. Introduction

The study of collisions between a pair of ultracold trapped has atoms aroused much interest recently. In the presence of near-resonant light fields, as usually found in molasses or optical traps, excited-state cold collisions show interesting properties as pure quantum-mechanical systems, but may cause undesirable losses in the density of cold atoms in the trap.[1] This fact has also renewed the interest in the collision. Among alkalis, the caesium has been widely studied, both theoretically and experimentally,[2−11] so that it represents a kind of benchmark for the alkali dimer family. In 1972, Klyucharev and Lazarenko[2] reported that when the Cs vapour was resonantly excited to the 6P levels, fluorescence from the 6D atomic level, which lay near to twice the 6P energy, could be observed. Collisions of this type have since been called 'energy pooling (EP) collisions'. In 1995, Jabbour *et al*[3] carried out an experiment on EP collisions of Cs $6P_J$+$6P_J$ →6S+nL(7P, 6D, 8S, 4F). They measured the atom densities and fluorescence ratios between various excited states, and obtained the corresponding cross section and coefficients. Recently we have reported on a scheme that locks the diode-laser frequency to the off-core peaks of EP fluorescence.[9] The EP retrofluorescence, which is spontaneously emitted near the boundary layer from highly excited states, such as $7P_J$ ($J = 3/2, 1/2$), shows two-off-core peaks in the wings. It is found that the temperature dependence of the two-peak shift enables us to tune the laser frequency in a large range. Here, we present the spectrum of EP retrofluorescence and the intensity-dependent effect of the two-peak profile under the condition of moderate-to-high optical depth at line-centre.

2. Experimental setup

The experimental setup is shown in Fig.1. Pure Cs vapour is contained in a T-shape sample cell, whose lower part is a Cs metal reservoir while the upper part

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is the main body filled with Cs vapour. The two parts are embedded in two copper blocks and heated to a programmed temperature. The Cs vapour pressure is controlled by the temperature of the lower part (between 80 °C and 120 °C). The lower part is kept at a temperature lower than the upper part by about 8 °C in order to prevent the Cs vapour from condensing on the windows.

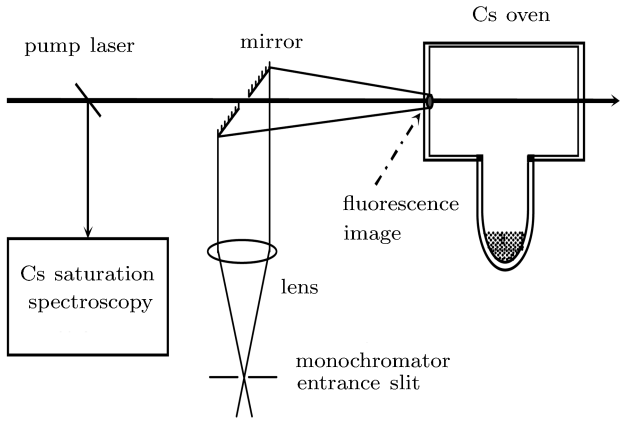


Fig.1. Experimental setup. The laser beam comes from an external cavity diode laser used to pump the $6S_{1/2} \rightarrow 6P_{3/2}$ transition. The monochromator is used to spectrally resolve the Cs atomic EP retrofluorescence. The saturation spectroscopy at room temperature serves as a standard wavelength scale for fluorescence.

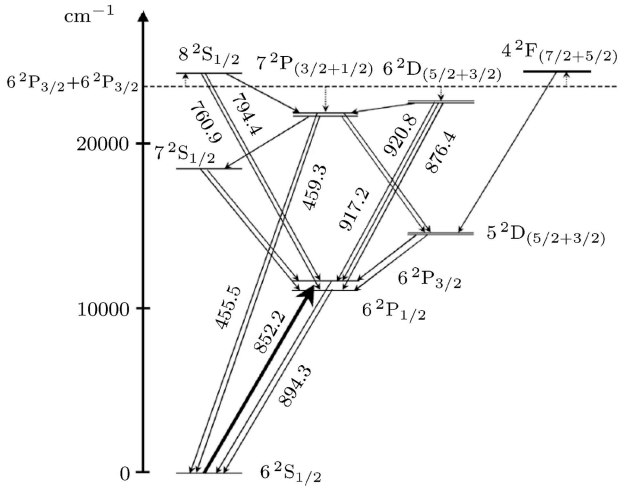


Fig.2. Diagram of energy levels of caesium atom. The horizontal broken line is located at twice the value of the excited $6P_{3/2}$ level energy. The wavelengths of the transitions are given in nm.

In our experiment, we use a diode laser (New Focus 6017) to populate the $6P_{3/2}$ level of Cs atoms in the cell. Only the fluorescence generated at the layer adjacent to the vapour oven interface is observed. The generated EP retrofluorescence selected by a 0.5m monochromator is recorded with a photomultiplier.

3. Results and discussion

From $T = 80\,^{\circ}\mathrm{C}$, we begin to observe the emissions due to EP collision: $\mathrm{Cs}(6P_{3/2}) + \mathrm{Cs}(6P_{3/2}) \rightarrow \mathrm{Cs}(nl_J) + \mathrm{Cs}(6S_{1/2})$, where nl_J is a highly excited level as shown in Fig.2. The Cs atom density N is determined using the formula given in Ref.[12] , which varies with temperature. We increase the cell temperature to $T = 120\,^{\circ}\mathrm{C}$, at which the corresponding Cs atom density $N = 3 \times 10^{13}\ \mathrm{cm}^{-3}$. At even higher densities, the secondary collisional processes[13] become important and may mask the energy pooling collisions. The number of EP spectral lines is about 16 at 120 °C of the atomic vapour temperature (Fig.3). All the spectral lines could be assigned to well-known Cs transitions as shown in Table 1. The EP fluorescence is not uniform in the propagating direction of the laser beam because the laser beam decays in the Cs atomic vapour.

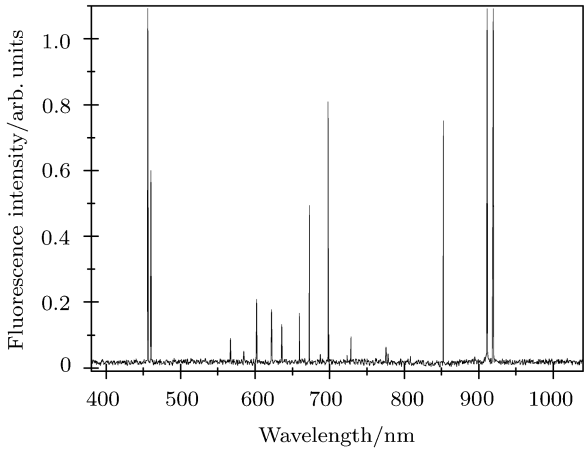


Fig.3. Spectrum of the EP fluorescence, which Cs temperature being 120 °C.

The populations of 8S, and 4F levels produced by energy-pooling collisions ($6P_{3/2}$+ $6P_{3/2}$) are not observed here because of the low atomic density.

We focused the laser beam near the window of the heated Cs vapour cell, adjusted the laser to a uniform intensity and then detuned it from the resonance frequency. The retrofluorescence signals were recorded as a function of laser detuning ν_{L} from the $6S_{1/2} \rightarrow 6P_{3/2}$ line centre. Figure 4 shows the 917.2 nm fluorescence spectra, with Cs oven temperature being 120 °C. The incident laser beam, respectively, has a power of (a) 14.2 mW and (b) 8.5 mW and is tuned around its centre frequency (the resonant 852 nm of Cs D_2 line) to provide a frequency scan covering a range of ±1.8 GHz.

Table 1. Wavelengths of the EP fluorescence assigned to the transition lines of the Cs atom.

Wavelength/nm	Transition line	Wavelength/nm	Transition line
455.5	$7P_{3/2} \rightarrow 6S_{1/2}$	658.6	$9S_{1/2} \rightarrow 6P_{3/2}$
459.3	$7P_{1/2} \rightarrow 6S_{1/2}$	672.3	$7\ D_{3/2} \rightarrow 6P_{1/2}$
566.4	$9D_{5/2} \rightarrow 6P_{1/2}$	697.3	$7D_{5/2} \rightarrow 6P_{3/2}$
584.5	$9D_{5/2} \rightarrow 6S_{1/2}$	722.8	$6F \rightarrow 5D_{3/2}$
601.0	$8D_{3/2} \rightarrow 6P_{1/2}$	727.9	$6F \rightarrow 5D_{5/2}$
603.4	$10S_{1/2} \rightarrow 6P_{3/2}$	852.1	$6P_{3/2} \rightarrow 6S_{1/2}$
621.3	$8D_{5/2} \rightarrow 6P_{3/2}$	917.2	$6D_{5/2} \rightarrow 6P_{3/2}$
635.4	$9S_{1/2} \rightarrow 6P_{1/2}$	920.8	$6D_{3/2} \rightarrow 6P_{3/2}$

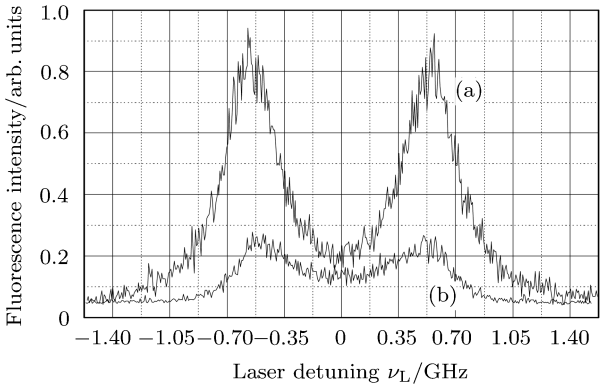


Fig.4. 917.2 nm EP fluorescence intensity as a function of laser detuning ν_L from the resonant 852 nm line centre with Cs temperature being 120 °C and incident laser power being (a) 14.1 nW and (b) 8.5 nW, respectively.

It is found that the 917.2 nm EP fluorescence shows two off-core peaks in the wings. In order to explain the effects of resonance loss EP effect, we simply take advantage of the variation of absorption length, $1/k(\nu_L)$ with detuning from the resonance frequency. The depth of laser penetration is determined by the exponential term with $k(\nu_L)$ varying with the laser frequency. The transmitted intensity of the laser beam through a length z of the vapour is given by $I(z, \nu_L) = I(0)[1 - g_D(\nu_L)]\exp[-k(\nu_L)z]$. Here, I (0) is the incident intensity, and g_D (ν_L) is the normalized Doppler lineshape function. One may therefore expect the losses of collisions will be largest for zero detuning where the nearly parallel moving atoms[9] in the wavelength-thickness ($\lambda/2\pi$) layer near the window, where the weak incidence photons were totally absorbed. However, such losses should become increasingly less significant as the laser is tuned further from resonance. As we tune away from line core the laser radiation penetrates more deeply into the cell, creating thermalization excited-states Cs atoms far away from the window.

It is found experimentally that all of the other EP lines have the two-peak aspect similar to that of 917.2 nm profile. The behaviour of the collision profiles at temperatures higher than 120 °C, strongly suggests that some more complex processes[13] occur, which have not been investigated here.

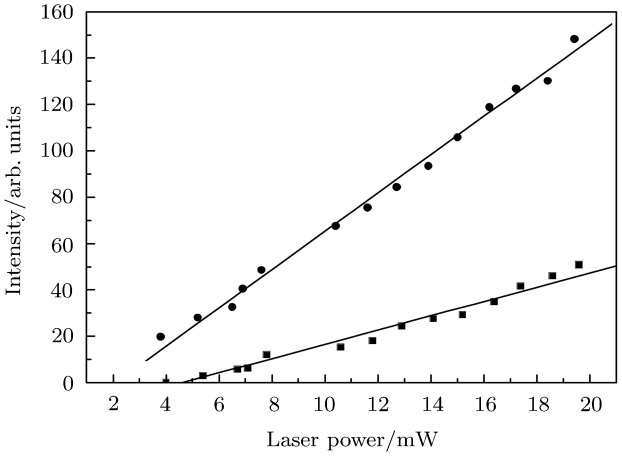


Fig.5. 917.2 nm EP fluorescence intensity as a function of pumping power, with Cs oven temperature being 120 °C. Circle (•) and square (■) represent the peak and dip intensities of the two-peak profile, respectively. The measurement error is within 10%.

The laser power change can affect the photon–atom interaction under the condition of moderate-to-high line-centre optical depth. Figure 5 shows the dependence of EP fluorescence on pumping laser intensity, with the Cs oven temperature fixed at 120 °C. The measurement error is within 10%. Note that the fluorescence intensity increases linearly as pumping laser power increases. We find that the slope of the dip intensity line is smaller than the slope of the line of peak intensities. It means that the contrast between the peak and dip is bigger at higher laser intensity. It is interesting to note that the separation between the two peaks does not change as the pumping laser

intensity changes, i.e. the separation is sensitive only to Cs oven temperature[9] but not to laser power.

4. Conclusions

We have performed sensitized EP fluorescence spectroscopic experiments to investigate the signal associated with $6P_{3/2} + 6P_{3/2} \rightarrow 7P_{3/2} + 6S_{1/2}$ energy pooling collisions in moderate-to-high line-centre optical depth caesium vapour excited by a diode laser tuned to the 852.2 nm $6S_{1/2} \rightarrow 6P_{3/2}$ resonance line. The experimental results reveal similarity of two-peak profile between the EP retrofluorescence lines. We have measured the pumping power linear dependence in the energy pooling process.

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