Oscillator Strengths of Rydberg Transitions

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1 Introduction

In the present extended abstract we will describe a novel experimental technique which allows the determination of absolute oscillator strengths of transitions into high-lying Rydberg states where in current experiments the main quantum number n varies from 30 to 60. The largest attainable upper quantum number is limited by the spectral width and the incremental scanning step size of the laser system. The lower limit of n results from the requirement that the ionization probability must be very nearly equal to unity for atoms being in a high Rydberg state. Absolute f-values are obtained from a measured photoionization cross section exploiting the fact that the discrete f-values are continuously merging into the differential ones.

2 Procedure

By means of laser spectroscopic techniques we investigate transitions from the Sr I $5s5p^1P_1^o$ resonance state into Rydberg states as well as into the continuum near the the first ionization threshold. The first laser is set to the resonance wavelength of 460.7 nm while the second laser is tuned over the Rydberg states into the continuum. Our experimental arrangement to study Rydberg lines has been described elsewhere (Willke and Kock 1991, Mende and Kock 1996). The detector for the laser-produced ions is our metal vapour oven designed as a thermionic diode. A cross section of our oven is given in Fig.1.

The oven was typically operated at a temperature of 520^{o}C with argon as a buffer gas at pressures between 10 and 15 hPa. At such pressures the ionization probability for Rydberg states with $n \geq 20$ is $p_n = 1$. For $n < 20$ it is no longer guaranteed that the ionization probability is still unity, thus setting a lower limit for our measuring procedure. As long as the condition, $p_n \simeq 1$, is fulfilled there is a simple relationship between f–value and photoionization cross section (see Mende and Kock 1996):

$$\frac{1}{4\pi\epsilon_0}\frac{\pi e^2}{mc} f_{1n} = \frac{S^{1n}}{S^{1+}}\frac{\nu_{1n}}{\nu_{1+}}\sigma^{1+} \quad . \tag{1}$$

The equation holds under the additional assumption that the absorption of the lines occurs in an optically thin layer. The f–value f_{1n} is then directly related to the photoionization cross section σ^{1+} measured at frequencies ν_{1+} and ν_{1n}, respectively, the ratio of the ion signals S^{1n} due to absorption in the line, and the direct absorption into the continuum, S^{1+}.

The necessary absolute photoionization cross section σ^{1+} at the first ionization threshold was determined with the saturation method (see e.g. Burkhardt *et al* 1988, He *et al* 1991, Mende *et al* 1995). Within the excited vapour column the second laser pulse, when tuned to a fixed wavelength

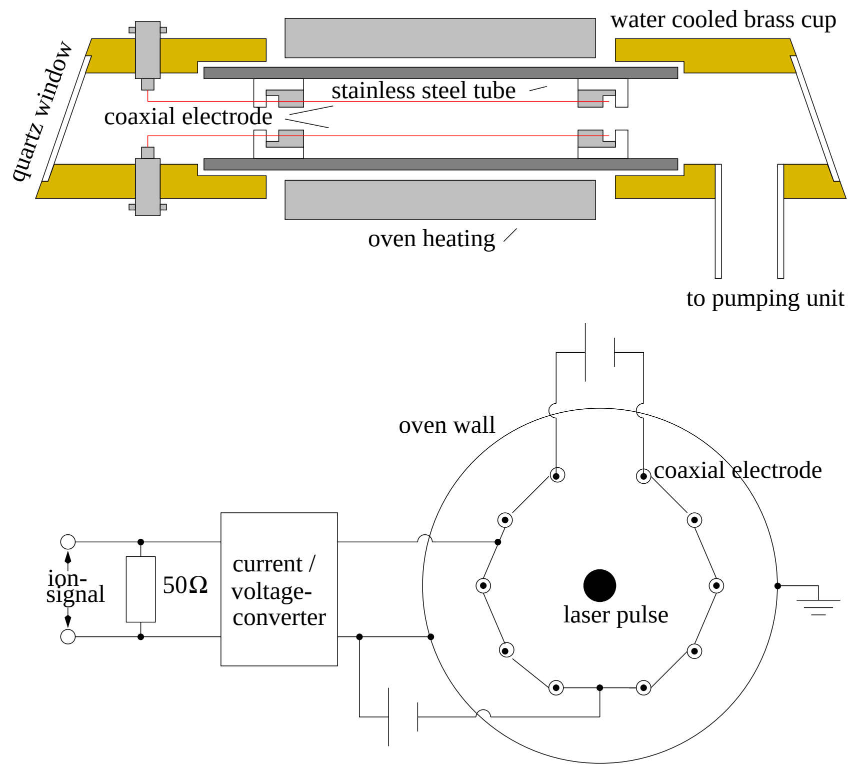

Figure 1: Cross sectional drawing of thermionic diode.

in the ion spectrum, produces the following number of photoions:

$$Z = \int_V N_o \left(1 - \exp\left(-\sigma^{1+} g(\rho)\phi\right)\right) dV \quad . \tag{2}$$

Here $g(\rho)$ is the spatial distribution of the laser pulse while ϕ is the time-integrated number of photons of the ionizing laser pulse. By fitting this expression to a saturation curve, N_o and σ^{1+} can be obtained on absolute scales provided the spatial distribution $g(\rho)$ is known. The influence of different spatial laser profiles $g(\rho)$ on saturation behaviour can be seen in Fig.2. A top-hat, a Gaussian and a modified Lorentzian function $g(\rho)$ are used with the saturation function given in equation (2):

$$\begin{aligned} g_{top-hat}(\rho) &= \frac{1}{\pi\Delta\rho^2} \quad \text{for} \quad \rho < \Delta\rho, \quad \text{else } 0 \quad . \\ g_{Gauss}(\rho) &= \frac{1}{\pi\Delta\rho^2} \exp\left(-\left(\frac{\rho}{\Delta\rho}\right)^2\right) \quad . \\ g_{Lorentz}(\rho) &= \frac{1}{\pi\Delta\rho^2} \frac{\Delta\rho^4}{(\rho^2 + \Delta\rho^2)^2} \quad . \end{aligned} \tag{3}$$

Only with a top-hat shaped laser pulse can complete saturation be achieved. Incidently, the wings in the Gaussian and Lorentzian curve are responsible for the fact that the curves in Fig. 2 do not reach complete saturation.

Fig. 3 displays a measured saturation curve together with a least-squares fit of equation (2). Note that it is not sufficient to describe the spatial distribution by a top-hat function. The actual distribution must be taken instead. We monitored the distribution with a CDD camera and fitted

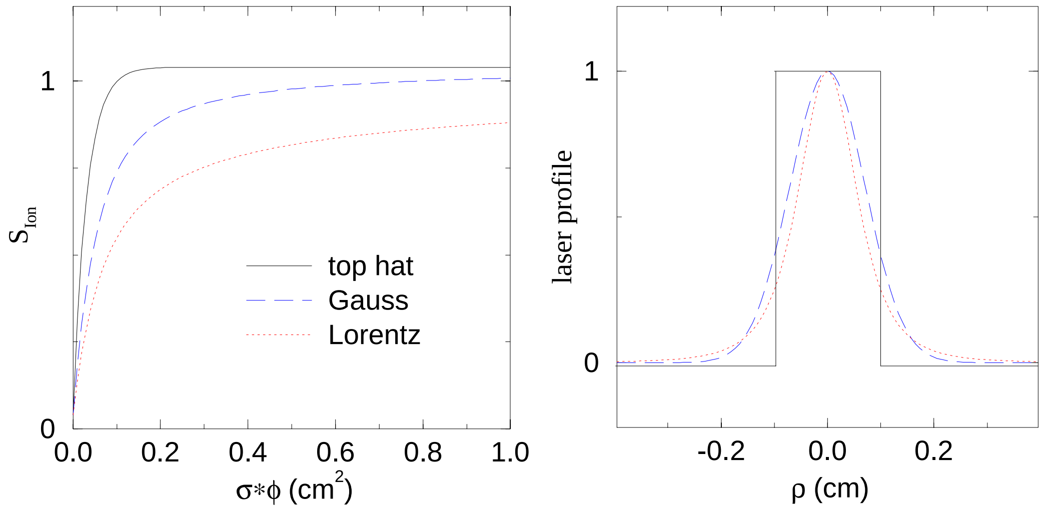

Figure 2: Saturation function with different spatial laser profiles.

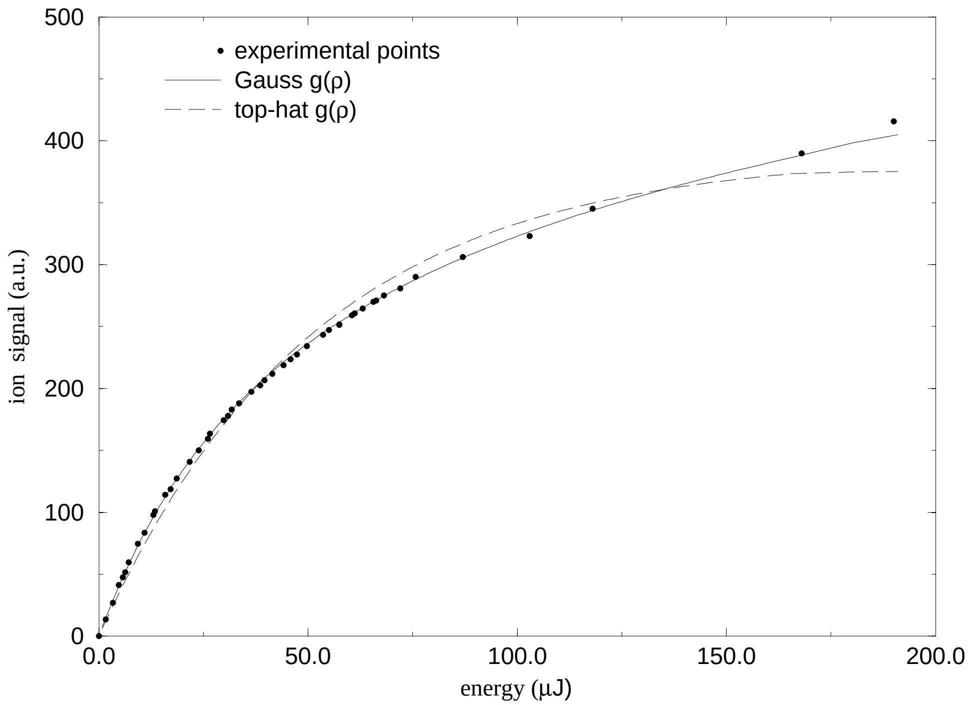

Figure 3: Saturation behaviour of the ion signal versus energy variation of the ionizing laser pulse at 412 nm. The full curve is a least-squares fit of the data points with the saturation function given in Eq. (2). Due to the wings of the Gaussian shaped laser pulse, complete saturation was not achieved.

it to a bell-shape curve. We have calibrated our f-values with the 176 Mb±20% cross section we found with the saturation technique. The accuracy to which we can determine absolute f-values is mainly limited by the saturation technique. Since only a small saturation could be obtained

Table1. Absolute oscillator strengths of the Sr I $5s5p\ ^1P_1^o \rightarrow 5snd\ ^1D_2$ transitions.

n	f-value	n	f-value
30	6.76E-4	46	2.44E-4
31	5.96E-4	47	2.46E-4
32	5.56E-4	48	2.50E-4
33	4.92E-4	49	2.19E-4
34	4.38E-4	50	2.02E-4
35	4.79E-4	51	2.13E-4
36	4.19E-4	52	1.88E-4
37	4.07E-4	53	1.77E-4
38	3.97E-4	54	1.65E-4
39	3.55E-4	55	1.57E-4
40	3.50E-4	56	1.55E-4
41	3.33E-4	57	1.32E-4
42	3.35E-4	58	1.28E-4
43	3.01E-4	59	1.23E-4
44	2.84E-4	60	1.01E-4
45	2.66E-4		

with our laser system, the uncertainty of 20% is relatively large. With higher laser energy available the uncertainty could be easily reduced to 10%. Nevertheless, in the present experiment it is the dominant contribution to the total uncertainty of $(22-24)\%$ in the f-values given in table 1 for the Rydberg transitions $5s5p\ ^1P_1^o \rightarrow 5snd\ ^1D_2$ with $n = 30 - 60$.

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