Oscillator Strength Measurement of Transitions Excited from a Metastable State Using Laser Optogalvanic Spectroscopy - Part 2: Experimental

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In the theoretical part of this work it was shown that it is possible, under certain particular conditions, to relate the optogalvanic signal magnitude (OGS) to the saturation parameter of electronic transitions of atoms contained in a hollow-cathode plasma. By fitting the theoretical expression to the OGS measurements as a function of the laser power, the product $\sigma_0\tau$ could be determined. As the absorption cross section is proportional to the oscillator strength of the transition, this last parameter could also be determined experimentally from measurements of the Doppler broadening of the absorption line and the saturation photon flux. This OG spectroscopy thecnique was used in this work to determine the oscillator strength of the $a\,^3P_0 \rightarrow y\,^3D_1{}^o$ Ti-I transition .

Introduction

An important relation between the optogalvanic signal amplitude and the laser power used to excite atoms in a hollow cathode discharge was presented in the first part of this work. This relation was obtained by considering excitation of atoms in a metastable level, assuming that the OGS amplitude is proportional to the density variation of this level due to the laser photon absorption. To summarize, the expressions that will be used to calculate the oscillator strength of the $a\,^3P_0 \rightarrow y\,^3D_1{}^o$ Ti-I transition in this work are $\Delta V = B/(1+J_s/J)$, where $J_s = 1/4\sigma_0\tau$ and $f_{23} = mc\Delta\nu_D\sigma_0/(e^2 2\sqrt{\pi}\ln 2)$ or $f_{23} = 10\Delta\nu_D/J_s\tau$. The first two equations were obtained from the solution of the rate equations, according to the theoretical development of the part 1. The third equation gives the oscillator strength of electronic transition of atoms that possess a maxwellian velocity distribution with a Doppler broadening $\Delta\nu_D$. The last equation was obtained by substituting the numerical values of the constants in the preceding equation. The f_{23} value for the titanium transition was determined in this work by measuring the saturation photon flux J_s and the Doppler broadening, using optogalvanic spectroscopy technique.

Experimental

A schematic diagram of the experimental set-up for the OGS measurements is shown in fig.1. The signal was induced in a titanium-argon home-made, water-cooled, hollow cathode tube. The geometry and the process of the tube construction are similar to the one described in ref. (1), except for the cathode element, that was replaced by a titanium plug. This plug was a cylindrical piece 23 mm long with a see-through hole 3.2 mm in diameter drilled on its axis. The tube was sealed with 2.5 Torr argon gas and was operated with a 125 mA stabilized dc discharge.

A ring dye laser (Spectra-Physics mod. 380A), with about 20 MHz linewidth, was tuned to the $a\,^3P_0 - y\,^3D_1{}^o$ Ti I transition in the 592.2 nm wavelength region. The lower level transition is a metastable one with energy of 8436.63 cm^{-1}. The upper level (25317.842 cm^{-1}) is strongly coupled by allowed dipole transitions to the ground state *(a* $^3F_2$ *)* and to many other intermediate levels as well. A multi-line Ar$^+$ laser (Spectra Physics mod.171) was used to pump the dye laser that operated with a Rhodamine 6G solution. The tuning and scanning of the laser wavelength was monitored by a wavemeter (Burleigh mod.WA-1000) with a precision of 0.001 nm. The entire scanning in the select frequency range and some eventual mode jumps could be observed on the wavemeter display.

The laser beam, that was modulated by a mechanical chopper (Stanford mod.SR540) at 37 Hz, matched the negative glow inside the cathode hole, with a diameter of about 3 mm. The optogalvanic signal induced by the laser was measured through a ballast resistor (1 kΩ) and a dc decoupling capacitor (1 pF) by a lock-in amplifier (Stanford mod.SR510) phase referenced to the chooper. The lock-in output signal was digitized and connected to a PC through a GPIB interface for storage and analysis.

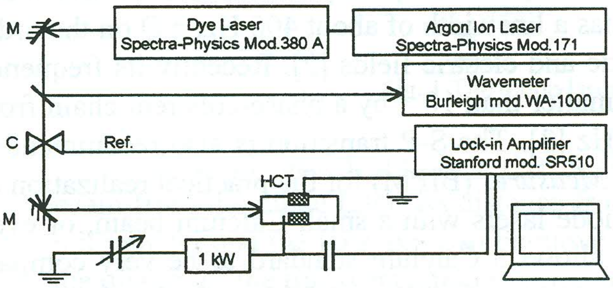

Fig.1 – Schematic diagram of the experimental set-up used for optogalvanic signal measurements. M: mirrors, BS: beam splitter; C: chopper; HCL= hollow-cathode tube.

Results and comments.

The results of the OGS are shown in fig.2, where the dots are the experimental data and the solid line is the fitted ΔV as a function of the laser power. The OGS amplitude, in arbitrary units scale, were measured at the absorption line peak by scanning the laser frequency in a 10 GHz range around this peak. By fitting the equation (7) of the part 1 to the experimental data the values of B and P_S where obtained. They are $B = 35$ and $P_s = 700$ mW, where P_S is the laser power saturation, for a 125 mA discharge current. As the area of the laser beam cross section is approximately 0.07 cm^2 and the photon energy is 2.09 eV, the saturation photon flux could be calculated as being $J_s = 3.0\text{x}10^{19}$ photons-cm^2/s. The Doppler broadening (1.5 GHz) was measured directly from the optogalvanic signal curve (see also ref.2). The total radiative lifetime is 14.5 ns, according to ref.3. From the equation that relates f_{23} to J_s, τ and $\Delta\nu_D$ (eq.10 of part 1) the oscillator strength could be determined and it is equal to 0.0344, that is in good agreement with the value of 0.0342 measured by Blackwell et al.$^{(4)}$ using another experimental technique.

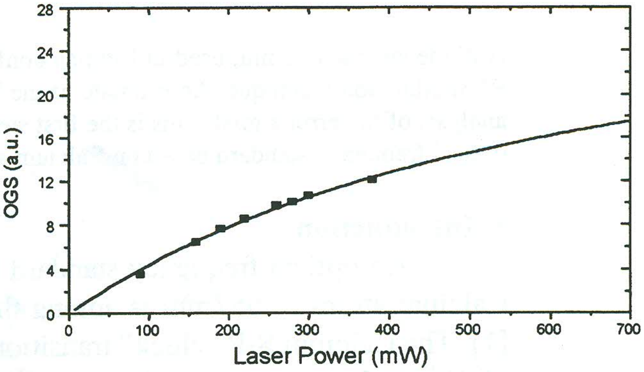

Fig.2 – Optogalvanic Signal amplitude as a function of the laser power. The dots are experimental points and the solid line is the adjusted theoretical curve.

Conclusion

It was shown that, under particular experimental conditions and in the case where a metastable level is excited by laser light, it is possible to measure the saturation parameter of the transition using optogalvanic spectroscopy techniques. Therefore, once the total radiative lifetime of the upper level is known, the oscillator strength and the absorption cross section of the transition can be determined. No attempt has been done to estimate the accuracy of such measurements, but the deviations that might occur on this experimental observations are mainly due to the errors introduced by the measurements of the laser power, the laser beam diameter and the Doppler line broadening.

Acknowledgement.

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