

# New energy levels of the La Atom found by a combination of several spectroscopic techniques

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We report on a combination of optogalvanic spectroscopy, laser-induced fluorescence (LIF) spectroscopy, emission spectroscopy using a grating monochromator, and Fourier-transform spectroscopy. The methods were used to search for up to now unknown energy levels of neutral La. As source of free La atoms, we use a hollow cathode lamp, for excitation the radiation of cw dye lasers operating with different dyes [1]. When exciting transitions to high-lying energy levels of the La atom by means of laser light, we noticed that optogalvanic (OG) spectroscopy is very sensitive, and one can observe much more lines than one would expect. For example, between 6808 and 6812 Å there is 1 line listed in the MIT wavelength tables [2], while we could excite 12 lines.

Thus we decided to make a continuous wavelength scan over a wide spectral region, using a cw dye laser, operating with R6G. It was possible to scan the laser from 610 to 560 nm. Altogether, more than 1500 spectral lines were found, most of them showing a nicely resolved hyperfine (hf) structure pattern. For the classification of these lines, we use a computer program 'Elemente' [3], which suggests transitions having the right wave number (within a chosen interval) and which shows expected hf patterns, since the hf constants of all known La levels meanwhile are determined. When no suggestion is given, we assume that a new, up to now unknown level is involved. In such case, we set the laser wavelength to the highest peak of the unclassified pattern and search for laser-induced fluorescence (LIF) lines. Here we have to distinguish between some cases:

(1) We find no fluorescence line. This may be the case if the excited transition is the only one strong line, or if the LIF lines are in the infrared or ultraviolet region outside our detection range. The excited transition stays unclassified.

(2) We find some LIF lines which are in phase with the chopped exciting laser light. This phase gives us the information that the emission of the LIF takes place from the upper level of the transitions. For finding more exactly the fluorescence wavelengths, we perform the following procedure: The laser wavelength is set to optimal excitation (with help of the OG signal). Then the monochromator dispersing the LIF light is scanned and gives a signal when LIF light passes to the photomultiplier. A second chopper in front of the monochromator entrance slit and a second Lock-In amplifier allows to record simultaneously the emission spectrum of the hollow cathode lamp. The recorded spectrum is then compared with a high-resolution Fourier-transform spectrum. In this way we can determine LIF wavelengths with an uncertainty of less than 0.1 Å, despite of the fact that the resolution of the monochromator is 0.5 Å and the reading of the monochromator scale is accurate to only  $\pm 2$  Å. Using all available information (excitation and LIF wavelengths, estimated J values and hf constants from a simulation of the observed hf pattern) it is in most cases possible to find the data of the new level involved in the transition.

(3) We find some LIF lines which have opposite phase compared to the chopped exciting laser light. Such lines are observed when the lower level of the laser excitation serves as the upper level of a strong transition to a very low-lying La level. The energy of the new level can be found by adding the transition wave number to the energy of the level marked by this LIF line.

(4) Sometimes we find a huge number of LIF lines (e.g. when exciting 6520.64 Å, more than 200 LIF-lines). In such cases we have to assume that the upper levels of the observed LIF transitions are populated by collisional energy transfer. Then it may be very difficult to find out where the new level is located.

The experiments are performed to have reliable data for a semi-empirical description of the wave functions of La levels.

## References

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[3] L. Windholz and G. H. Guthöhrlein, Physica Scripta T105, 55 (2003)