VUV photoabsorption spectra of Pb and Bi ions using dual laser plasma technique

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Abstract. The report concentrates on a study of vacuum ultraviolet (VUV) photoabsorption spectroscopy of metal atoms and ions using laser plasma generated continuum radiation. The absorption spectra of lowly charged ions of lead and bismuth have been obtained using the Dual Laser Plasma (DLP) photoabsorption technique. While the RTDLDA code of Zangwill provides a good approximation to the overall spectral shape, the Cowan suite of codes, with input parameters tuned by comparison with spectral lines already identified in the literature are needed to identify unknown lines.

1. Introduction
The DLP technique [1] is a highly useful experimental procedure to investigate the VUV/XUV photon interactions in a wide range of atoms and ions. It also provides a flexible approach to the study of inner-shell and multiple electron excitations in atoms and ions. Solid targets and refractory elements can be explored with this experimental method. A continuum emitting plasma is used as a backlighting source to a second absorbing plasma containing the atomic or ionic species of interest. There are three critical parameters which dictate ion stage selectivity in any DLP photoabsorption experiment. (1) the laser conditions, (2) the time delay between the formation of absorbing and backlighting plasmas and (3) the displacement of the sample target surface from the system’s optic axis. By changing the time delay between the two plasmas and the position of the absorbing plasma with respect to the optical axis, time and spatial resolved photoabsorption studies, from virtually any material plasma, can be performed using this technique.

2. Experimental setup and methods
The output of a pulsed Nd:YAG laser (400 mJ in 15~20 ns) is focused onto a tungsten rod to generate the back-lighting plasma. The absorbing plasma was generated by a Continuum Surelite Q-switched laser system. The laser pulse carries an energy of 450 mJ with a FWHM of 6 ns. In the experiment the plasma radiation passes through the fore-slit in the target chamber and subsequently is incident on the adjustable entrance slit which is fixed to the entrance arm of the 1m normal incidence spectrometer. It is dispersed with the aid of a 1200 grooves/mm Bausch & Lomb™ spherical concave holographic grating mounted within the spectrometer chamber which is operated in an off-Rowland circle type configuration. In this configuration scanning of dispersed radiation across the detector plane is achieved through rotation of the grating, while focusing is maintained by linear translation of the grating. A 2-D Andor™ back-thinned CCD detector is used to record the absorption and emission spectra.
In the experiment, the continuum spectrum \( (I_0) \) is obtained by firing the back-lighting laser only while the transmitted intensity \( (I) \) is recorded by firing both lasers. The absorption data can be obtained from \( \ln(I/I_0) \) according to the Beer-Lambert Law. The experimental spectra are calibrated by comparing with benchmark aluminium spectral lines.

3. Results and discussion

By appropriate choices of laser irradiation conditions, position of the absorbing plasma with respect to the optical axis and the time delays between continuum plasma and absorbing plasmas, the photoabsorption spectra of atomic (Bi I) and singly ionized (Bi II) have been obtained.

In figure 1, the black curve is our experimental data, and the blue curve is from Mazzoni’s paper [2] and the coloured lines are Bi I lines from different papers. The cyan lines are the photoionization spectrum of Bi I measured by Yoo et al [3] while the blue lines are Bi I observed by Mazzoni et al [2]. The red lines are Bi I recorded by Joshi et al [4]. We have quite good agreement in the 75-88 nm and 106-117 nm ranges with the literature. In the 52-55 nm range large resonances due to 5d to 6p transitions are observed.

Figure 2 shows the photoabsorption spectrum of Bi II. The coloured lines are from different papers, the green lines are the absorption spectrum of Bi II obtained by Joshi et al [4] while the magenta lines are measured by Andrzejewska et al [5] in 2013. The blue lines are Bi II from the NIST database while the cyan lines are Bi II recorded by Wahlgren et al [6]. We have good agreements with the literature.

The RTDLDA code [7] has been used to calculate the absolute cross sections of Bi and Bi\(^+\). Figure 3 shows the comparison of our experimental data and the RTDLDA results. The black curve is the photoabsorption spectrum of Bi and the red dots show the RTDLDA computed cross section. The calculation matches the broad feature of our experiment and it also shows the 5d to 6p transitions at 52.6
nm. Figure 4 is the comparison of experiment data and the RTDLDA results for Bi$^+$. The RTDLDA calculation cannot obtain the discrete features of the spectrum. Cowan’s suite of atomic structures codes [8] will be used to identify the discrete features of the spectrum.

![Figure 3](image-url)  
**Figure 3.** Comparison of experiment and RTDLDA calculation of Bi I.

![Figure 4](image-url)  
**Figure 4.** Comparison of experiment and RTDLDA calculation of Bi$^+$. 

### 4. Conclusions

In summary, the lines of Bi I and Bi II have been isolated and they have generally good agreement with the literature. The absolute cross sections have been calculated to compare with our experiment data for the broad features. In future, Cowan’s suite of atomic structure codes will be used to help assign the remaining unidentified lines.

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