Absolute Measurement of the Resonance Lines in Helium-like Vanadium on an Electron Beam Ion Trap

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The first absolute measurements of the energies of resonance lines in helium-like vanadium on an electron beam ion trap (EBIT) are reported. The measurements were conducted at the NIST EBIT[1] and the unique spectroscopic advantages of the EBIT have been crucial in the success of these QED investigations, allowing Doppler free and low satellite contamination spectra to be measured[2]. The absolute calibration is achieved by using a spread of characteristic wavelengths ($K\alpha$ and $K\beta$), to map out and rigorously determine the dispersion function of the spectrometer. We have developed the dynamical diffraction theory necessary to evaluate systematic shifts at the precision level required to test QED in this regime[3, 4, 5]. Systematic shifts associated with the shape and location of the detector used in the Johann geometry have been evaluated and reduced to a level that is comparable to the uncertainty of the reference wavelengths used for calibration[6].

The $1s2p\ ^1P_1 \rightarrow 1s^2$, $1s2p\ ^3P_2 \rightarrow 1s^2$, ($1s2p\ ^3P_1 \rightarrow 1s^2$ and $1s2p\ ^3P_0 \rightarrow 1s^2$) blend and $1s2s\ ^3S_1 \rightarrow 1s^2$ transitions are 5205.10±0.14 eV, 5189.12±0.21 eV, 5180.22±0.17 eV and 5153.82±0.14 eV respectively. This agrees with recent theoretical calculations[7, 8] and the experimental precision lies at the same level as the current uncertainty in theory (0.1 eV)[9]. These measurements represent a 5.7%–8% determination of the QED contribution to the transition energies and are the most precise measurements of helium-like resonance lines in the $Z = 19$–31 range. Figure 1 shows a survey of measurements of the $1s2p\ ^1P_1 \rightarrow 1s^2$ transition in the medium Z region, indicating the relative precision of our measurement at $Z = 23$. Our measurement of the $1s2p\ ^1P_1 \rightarrow 1s^2$ transition in vanadium does not support a reported trend that experimental energy values are greater than theory [10, 11]. Our measurement of the $1s2s\ ^3S_1 \rightarrow 1s^2$ transition is also sensitive to the $1s2s\ ^3S_1$ QED contribution at the 40% level.

The hyperfine-induced decay of the $1s2p\ ^3P_0$ level to the ground state in vanadium cannot be resolved from the $1s2p\ ^3P_1 \rightarrow 1s^2$ transition in any available experimental method[12]. The relative intensities of the $1s2p\ ^3P_0 \rightarrow 1s^2$ and $1s2p\ ^3P_1 \rightarrow 1s^2$ transitions therefore shift the observed centroid of the blend. The intensity of the strong $1s2p\ ^3P_1 \rightarrow 1s^2$ component of the blend compared to the total blend intensity is determined to be $94\% \pm 12\%$. This is in accord with current theoretical predictions but disagrees with an earlier reported ratio[12]. The benefits of absolute calibration and rigorous diffraction theory combined with an EBIT spectroscopy source in precision tests of QED have been demonstrated. There is now the potential to probe discrepancies between theories in the medium Z range using these methods.

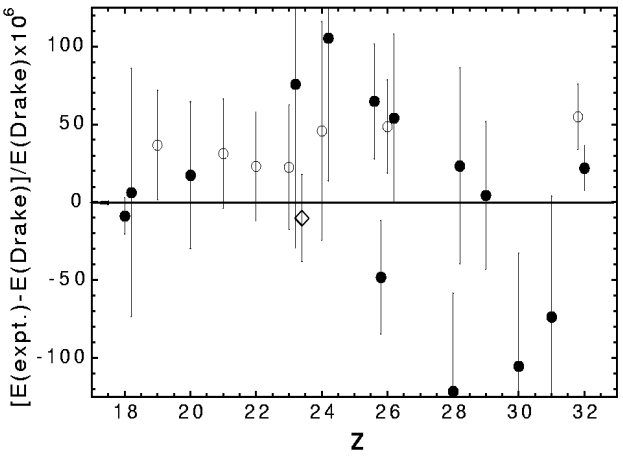

Figure 1: Measurements of the transition in medium Z ions: comparison to theoretical work of Drake [7].
$\diamond$ This work, conducted on the NIST EBIT; $\bullet$ other sources; o Beiersdorfer *et al.* [10], conducted on a tokamak plasma, and $Z = 32$ MacLaren *et al.* [11], conducted on the Lawrence Livermore National Laboratory EBIT: reported trend of experimental energies higher than theory.

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