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Wavelength measurement of the $1s2s\,^3S_1$-$1s2p\,^3P_2$ transition in heliumlike Fe^{24+}

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The wavelength of the transition $1s2s\,^3S_1$-$1s2p\,^3P_2$ of heliumlike Fe XXV has been measured in beam-foil-excited spectra at 7 MeV/nucleon. The result is $\lambda(2\,^3P_2-2\,^3S_1)=271.02\mp0.09$ Å. The present wavelength measurement is sensitive to Lamb-shift contributions alone to a precision of $\mp3\%$.

The measurement of the $\Delta n=0$ transition energies can lead to sensitive testing of quantum electrodynamics (QED) and relativistic corrections for higher-Z two-electron ions.[1] With high Z, the nonrelativistic energy becomes a smaller fraction of the transition energy and electron-correlation parts are reduced for the QED and relativistic contribution corrections. In the first beam-foil spectra of high-energy ion beams[2] the transitions $2s\,^3S$-$2p\,^3P$ were observed in low-Z two-electron atoms C V, N VI, O VII, and Ne IX. The result for the center of gravity of Ne IX was found to deviate significantly from the center of gravity given by Wiese *et al.*[3] The fine-structure splittings were not resolved. Davis and Marrus[4] made the first $2s\,^3S$-$2p\,^3P$ observation of heliumlike ions with $Z\geqslant10$ in Ar XVII at wavelengths 560 and 661 Å, measured with limited precision of ∓1 Å. Higher precision was obtained in lower-Z elements by Berry *et al.*,[5] on Cl^{15+}, by O'Brien *et al.*,[6] on Si^{12+} and by Livingston *et al.*[7] on Si^{12+}, S^{14+}, and Cl^{15+}. All the results have a precision of ∓0.1 Å in wavelength and show agreement with the theoretical values of Berry *et al.*[8]

We report here on the wavelength measurement of the $1s2s\,^3S_1$-$1s2p\,^3P_2$ transition in two-electron Fe^{24+}.

The heliumlike iron spectra were excited in fast iron beams from the hybrid accelerator ALICE at Orsay using the conventional beam-foil techniques. At 395 MeV (7 MeV/nucleon), the charges emerging out of a 160-μg/cm^2-thick carbon foil are almost equally distributed amongst two-electron ions, three-electron ions, and other ions, mainly with four and one electrons. The choice of such an energy is to obtain a high fraction of excitation of heliumlike ions (of first interest) and of lithiumlike ions to serve as reference lines. The spectra were studied by means of a Roman-Vodar 3-m vacuum monochromator equipped with an aluminum-coated ruled grating blazed for 250 Å. The observation was made at 90° to the ion beam. The spectrometer wavelength drives were controlled by a stepping motor. The detector was a channeltron, counting emitted photons for a given step during a time monitored on the particle charge measured in a Faraday cup.

A partial spectrum of the light emitted by the iron beam just at the carbon foil exit is shown in Fig. 1. The slit width was 150 μm, the full width at half maximum (FWHM) about 1.4 Å, and the scan increment about 0.2 Å. In the wavelength region ranging from 250 to 283 Å, the $2s$-$2p$ transition appears surrounded by several lines used as references. The identification of these lines is based on the study of the whole spectrum we have recorded from 115 to 480 Å with wider slits (300 μm) and a larger scan increment. This procedure is used to be sure of our identification of higher-order spectra. Principal features are the very strong doublet $2s$-$2p$ in lithiumlike Fe XXIV, the $2s2p$-$2p^2$ lines in beryliumlike Fe XXIII, and the hydrogenic lines, here 5-6, 6-7, 7-8, and 8-9 in one-, two-, three-, and four-electron ions, which are a constant characteristic of all beam-foil spectra.

Of particular importance are the $n=5$-6 transitions in Fe XXIV which are observed in second order at the low-wavelength side of the $2s$-$2p$ Fe XXV line. The absolute wavelength of this calibration line has been calculated from relativistic hydrogenic energies for $6h, 6g, 6f$ and $5g, 5f$ levels corrected by the core-polarization contribution.[9] The static mean wavelength $\bar{\lambda}$ is found using hydrogenic transition probabilities and assuming statistical population distributions. A significant blue shift is due to the first-order

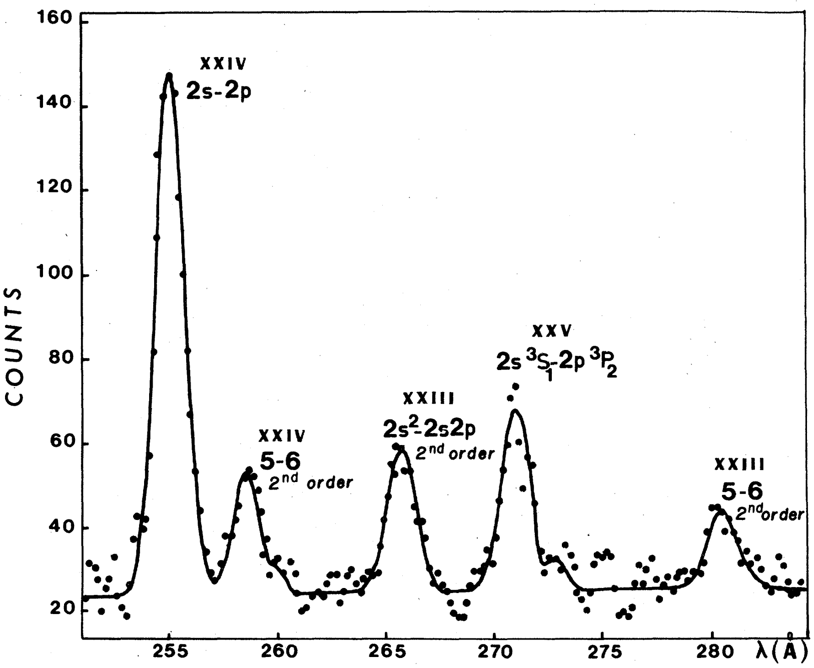

FIG. 1. Wavelength scan from 253 to 284 Å including the Fe XXV $2s\,^3S_1$-$2p\,^3P_2$ transition. Iron beam energy is 7 MeV/amu. The solid line represents a fit using Gaussian profiles.

Doppler shift because the lifetimes of $n=6$ levels are short compared to the time of flight of ions along the beam volume which is sighted by the monochromator (more than 1.3 mm). The red transverse Doppler shift has been taken into account. The real hydrogenoid Fe XXVI $n=7$-8 transitions have a better-known theoretical wavelength and a smaller Doppler shift, but we did not use them as references because of their small intensity and overlap with the Fe XXII $n=5$-6 transitions in second order.

Analyses using a Gaussian fitting program or other deconvolution procedures are in good agreement with the position of the heliumlike $2s\,^3S_1$-$2p\,^3P_2$ transition relative to the calibration line $n=5$-6 (∓ 0.005 Å). The error in absolute wavelength measurement due to the change in the calculated value of $\bar{\lambda}$ when assuming different population distributions is small. For a constant, $2l+1$ or l^2 distribution, the value of $\bar{\lambda}$ is displaced by about 0.01 Å. The uncertainty in absolute measurement is mainly due to the error in estimation of the apparent wavelength of reference line Fe XXIII $n=5$-6.

The result for the $2s\,^3S_1$-$2p\,^3P_2$ wavelength measured on this high-resolution spectrum is 271.01 ∓ 0.06 Å if no other systematic and statistic errors are taken into account.

Six more scans of the same spectral range (250–285 Å) have been recorded with wide slits (300 μm) and large increments ($\cong 0.5$ Å). They have been fitted to sums of Gaussian profiles. The six fits for the wavelength separation of the $2s\,^3S_1$-$2p\,^3P_2$ Fe XXV transition and the $n=5$-6 Fe XXV calibration transition have a mean-square deviation $\sigma=0.07$ Å about the weighted mean wavelength at 271.03 Å. This mediocre reproducibility may be due to the partial blending of the reference line with the strong $2s\,^2S_{1/2}$-$2p\,^2P_{1/2}$ Fe XXIV transition and difficulties in deconvoluting these low-statistics spectra. Our final result including both high- and low-resolution spectra is 271.02 ∓ 0.09 Å.

In Table I we compare our result with theory. The nonrelativistic energy has been calculated using the Z-expansion coefficients from Blanchard.[10] The convergence is rapid so that it is sufficient to limit the expansion to the Z^{-2} term to obtain a precision better than 1 cm^{-1}. The relativistic part is given as a double expansion in $1/Z$ and $(\alpha Z)^2$. We have included the relativistic hydrogenic terms in $(\alpha Z)^4$ and $(\alpha Z)^6$, the Breit term in $Z^{-1}(\alpha Z)^4$ as given in Doyle[11] and the $Z^{-2}(\alpha Z)^4$ term extrapolated from Mohr.[12] The mass polarization correction is extrapolated from Accad and Pekeris[13] and Ermolaev and Jones.[14] The quantum-electrodynamic part in Table I is obtained from the one-electron calculations of Mohr[15] and Garcia and Mack.[16] Differences with recent calculations of Berry[17] are small compared with the one-electron QED term, but the measured transition energy is less than the calculated values by about 400 cm^{-1}. A result giving a theoretical value lower than the experimental one has been previously published

TABLE I. $2s\,^3S_1$-$2p\,^3P_2$ transition in heliumlike Fe^{24+}. (Experimental energy uncertainty is in parentheses.) NR denotes nonrealitivistic and R denotes realitivistic.

Experiment		Theory			
λ (Å)	E (cm^{-1})	NR (cm^{-1})	NR + R (cm^{-1})	NR + R + QED (cm^{-1})	QED (cm^{-1})
271.02 ∓ 0.09	368 976(125)	209 977	372 859[a] 372 749.2[b]	368 653[a] 368 527.1[b]	4206[a] 4222.1[b]

[a] Details of these calculations are given in the text.

[b] H. G. Berry (private communication).

for lower Z by Berry.[8] However, the accuracy of our measurement is not really sufficient to test the reliability of this trend.

This first measurement of the $^3S_1$-$^3P_2$ transition for Fe XXV represents preliminary results. The wavelength has been determined within an error of 3×10^{-4}, making it possible to determine QED corrections, which in Fe XXV $2s$-$2p$ amount to about 2% of the transition energy with uncertainty as low as 3%. Future experiments are planned at Orsay with greatly improved experimental conditions to obtain a smaller linewidth, better statistics, and higher precision in reference wavelengths. They are expected to provide an accurate test of QED contributions when better relativistic calculations become available.

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