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Measurements of 2s-2p Transition Energies in Helium-like
and Lithium-like Nickel*

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The wavelength of the fine structure transition $1s2s\ ^3S_1 - 1s2p\ ^3P_2$ in Ni XXVII has been measured using fast-ion spectroscopy. The transition energy is sensitive to relativistic and Lamb shift corrections in this high-Z two-electron system. Comparison is made with measurements in other high-Z ions and with recent theoretical calculations. A preliminary measurement of the $1s^22s\ ^2S_{1/2} - 1s^22p\ ^2P_{1/2}$ fine structure transition in Ni XXVI is also reported.

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Measurements of 2s-2p transition energies in highly-ionized two-electron atoms provide tests of relativistic and Lamb shift effects in the strong nuclear Coulomb fields of these simplest multielectron systems. The most precise such measurements in high-Z helium-like ions [1] are sensitive to the total Lamb shift contributions at the 1% level, which is comparable to the precision of n=2 Lamb shift measurements in high-Z one-electron ions [2]. For the helium-like $1s2s\ ^3S_1 - 1s2p\ ^3P_2$ transition, screening corrections at $Z\sim 20-30$ are expected to contribute $\sim 5\%$ to the Lamb shift, or ~ 500 ppm to the transition energy [1,3-5]. Previous measurements of this transition energy for $Z>17$ [6-11] are of sufficient precision to be just sensitive to the screening effects, and show marginal agreement with calculated values. The present result for nickel ($Z=28$) represents the most precise high-Z test to date of calculated 2s-2p transition energies in two-electron systems.

The nickel spectrum was studied using fast-ion spectroscopy of foil-excited 350 MeV nickel ions at the Argonne ATLAS facility. The incident Ni^{11+} beam of a few particle-nanoamperes was ionized and excited by a $200\mu\text{g}/\text{cm}^2$ carbon foil. The fluorescence emitted nearly perpendicular to the beam axis was observed using a 2.2 meter grazing incidence monochromator (McPherson 247) with a windowless photon-counting detector (Channeltron). Spectra were measured with a wavelength resolution of $\sim 0.6\text{\AA}$ over the region 100-400 \AA , with concentration on the region 150-250 \AA . Computer-controlled wavelength

stepping was normalized to ion charge collected in a Faraday cup beam stop. The instrumental wavelength scale was established by measuring the wavelengths of well known helium and neon lines produced in a Penning discharge source. The Doppler-corrected wavelength scale was determined using selected in-beam reference lines from highly-ionized nickel.

A section of the spectrum of nickel is shown in fig. 1. The helium-like $2^3S_1 - 2^3P_2$ transition and the lithium-like $2^2S_{1/2} - 2^2P_{1/2}$ transition both are observed. The lithium-like $n=5-6$ hydrogenic transition, appearing in second order of dispersion, is characteristic of transitions for which the wavelengths are calculable with sufficient accuracy to be used as reference lines. These polarization correction calculations are discussed in refs. [1,8]. The $2^1S - 2^1P$ beryllium-like resonance transition has been measured recently in a tokamak plasma [12]. The beryllium-like $n=5-6$ hydrogenic transition possesses structure that precludes its use as a reliable reference line at our level of precision [13,14]. The wavelengths of the reference lines used in this analysis are listed in table 1.

A total of eight nickel wavelength scans was used to determine the results quoted here. Our result for the $2^3S_1 - 2^3P_2$ transition wavelength in helium-like nickel is $226.27 \pm 0.04 \text{ \AA}$, a 180 ppm measurement. Our preliminary result for the $1s^22s^2S_{1/2} - 1s^22p^2P_{1/2}$

transition wavelength in lithium-like nickel is $234.11 \pm 0.06 \text{ \AA}$. The quoted errors reflect approximately equal contributions from statistics and from uncertainties in the wavelength scale, the latter arising from calibration errors as well as imprecise knowledge of reference wavelengths.

The result for the helium-like $2 \text{ }^3\text{S}_1 - 2 \text{ }^3\text{P}_2$ transition in nickel is compared in table 2 with available calculated values for $Z=28$. Good to excellent agreement is apparent among all the results. Our present experimental uncertainty is identical to the theoretical error quoted in ref. 3 as an estimate of the size of uncalculated higher order relativistic and Lamb shift screening terms. This uncertainty is equal to about one-third the magnitude of the Lamb shift screening contribution. The present result appears to verify the accuracy of theoretical calculations for the $2 \text{ }^3\text{S}_1 - 2 \text{ }^3\text{P}_2$ transition energy above $Z=17$ (at least to $Z=28$). Similar comparisons are needed for the $2 \text{ }^3\text{S}_1 - 2 \text{ }^3\text{P}_0$ fine structure transition, for which there are no reliable measurements above $Z=18$, especially in view of the apparent discrepancy between experiment and theory for $Z=16$ [1,16].

Our preliminary result of $234.11 \pm 0.06 \text{ \AA}$ for the lithium-like $2s \text{ }^2\text{S}_{1/2} - 2p \text{ }^2\text{P}_{1/2}$ transition wavelength compares favorably with the recent tokamak measurement [12] of $234.14 \pm 0.02 \text{ \AA}$, as well as with a semi-empirical value [15] of 234.09 \AA and a variational screening value [18] of 234.15 \AA . In particular, however, it should be noted that

measurements of the lithium-like $2s-2p$ transitions at high Z may now be compared with very recent many body perturbation theory calculations [17] to isolate the associated Lamb shift screening contributions even more accurately than in helium-like ions. For example, these screening corrections appear to contribute about 10% of the total Lamb shift in Ni XXVI. Clearly, precise measurements of these important transitions for $Z > 36$ are strongly motivated by the new calculations.

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References

- [1] R. DeSerio et al, Phys. Rev. A 24 (1981) 1872.
- [2] H. Gould and R. Marrus, Phys. Rev. A 28 (1983) 2001.
- [3] S. P. Goldman and G. W. F. Drake, J. Phys. B 17 (1984) L197;
G. W. F. Drake, private communication.
- [4] J. Hata and I. P. Grant, J. Phys. B 17 (1984) 931; 16 (1983) 523.
- [5] P. Indelicato et al, J. Phys. B (1987) 651.
- [6] J. P. Buchet et al, Phys. Rev. A 23 (1981) 3354.
- [7] J. P. Buchet et al, Nucl. Instrum. Meth. B 9 (1985) 645.
- [8] E. J. Galvez et al, Phys. Rev. A 33 (1986) 3667.
- [9] S. J. Hinterlong and A. E. Livingston, Phys. Rev. A 33 (1986) 3670
- [10] H. F. Beyer et al, Z. Phys. D 1 (1986) 65.
- [11] S. Martin et al, Phys. Rev. A 35 (1987) 2327.
- [12] E. Hinnov et al, J. Opt. Soc. Am. B 4 (1987) 1293.
- [13] A. Mazure et al, Phys. Rev. A 32 (1985) 3775.
- [14] Y. N. Lu et al, these proceedings.
- [15] B. Edlén, Phys. Scripta 28 (1983) 51 ; 32 (1985) 86.
- [16] E. J. Galvez, Ph.D Thesis (1986), Notre Dame University.
- [17] W.R. Johnson, S.A. Blundell, and J. Sapirstein, to be published,
see also J. Sapirstein, these proceedings.
- [18] H.G. Berry et al, Phys. Rev. A 22 (1980) 998.

Table 1. Wavelength values (in Å) of reference lines used in this work:
 (a) ref.15, (b) ref.12, (c) calculated.

<u>Spectrum</u>	<u>Transition</u>	<u>Wavelength</u>	<u>Source</u>
XXV	$2s2p\ ^3P_2 - 2p^2\ ^3P_2$	151.86 ± 0.03	a
XXVI	$2s\ ^2S_{1/2} - 2p\ ^2P_{3/2}$	165.40 ± 0.02	b
XXVI	6 - 7	182.75 ± 0.04	c
XXVII	5 - 6	102.11 ± 0.02	c
XXVI	5 - 6	110.13 ± 0.02	c
XXV	$2s^2\ ^1S_0 - 2s2p\ ^1P_1$	118.00 ± 0.01	b
XXV	$2s2p\ ^3P_2 - 2p^2\ ^1D_2$	120.52 ± 0.02	a

Table 2. Comparison of experimental and theoretical values for the $2\ ^3S_1 - 2\ ^3P_2$ transition wavelength (in Å) in helium-like Ni XXVII : (a) ref.3, (b) ref.1, (c) ref.4, (d) ref.5.

a. 226.28 ± 0.04

b. 226.27

c. 226.25

d. 226.32

This work 226.27 ± 0.04

Figure Caption

Fig. 1. Section of fast-ion spectrum of highly-ionized nickel.

