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Isotope Shift in $^{151,153}Eu^+$ From High-precision Hyperfine Structure Measurements*

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Isotope shift in the two stable isotopes of Eu^+ has been obtained for four optical transitions between the states $4f^7(^8S^0)5d\ ^9D_J^0$ and $4f^7(^8S_{7/2}^0)6p_{3/2};J'$ using high-precision hyperfine structure measurements in a collinear laser and slow ion beam (1.35 keV) apparatus.

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1. INTRODUCTION :

Isotope shift [1] ($\delta\nu_i^{AA'}$) between two isotopes of mass A and A' in an optical transition i at a frequency ν_i arises due to two effects:

1) Mass shift from the change of nuclear mass and 2) Field shift from the change of size and shape of the nuclear charge distribution.

Thus, Isotope shift = Mass shift + Field shift

$$\text{i.e.,}\quad \delta\nu_i^{AA'} = M_i \frac{A' - A}{A'A} + F_i\,\delta\langle r^2\rangle^{AA'}$$

where M_i and F_i are the electronic factors characteristic of the transition i and $\delta\langle r^2\rangle = \langle r'^2\rangle - \langle r^2\rangle$ is the change in the mean square charge radii of the two isotopes. The mass shift (normal + specific) when separated from the isotope shift gives the field shift and information on nuclear size can be obtained from it.

2. METHOD :

Optical transition frequencies observed for two different isotopes in collinear laser-ion beam spectroscopy are separated by isotope shift and the differential Doppler shift. The latter is determined experimentally [2] (without having to know the ion velocity) from laser-induced fluorescence spectra taken with the laser and ion beam parallel and anti-parallel with each other, and when subtracted from the observed separation of the center of gravity of the two hyperfine structures gives the isotope shift.

3. EXPERIMENT :

The isotope shift measurements in four optical transitions in $^{151,153}Eu^+$ were performed with a newly built collinear laser and slow ion beam apparatus.The ions were produced in an arc discharge ion source

(Colutron) and mass separated by a 90° magnet and merged with a tunable dye laser collinearly. Both the stable isotopes of Eu^+ (nuclear spin I=5/2) have odd mass numbers and exhibit complex hyperfine structure. The hyperfine spectra for each isotope were recorded by laser-induced fluorescence and the transitions were well resolved and identified. Typical linewidths were 48-75 MHz. Then, with rf-double resonance technique [3,4] the magnetic dipole hyperfine constant (A) and the quadrupole hyperfine constant (B) were determined (see ref. [4] for details) with very high precision (within a few kHz). From this information the center of gravity of each hyperfine structure was determined accurately.

For the measurement of isotope shift, it was possible to pass a mixture of the two isotopeic ions through the interaction region by deliberately degrading the mass resolution of the magnet and with the help of the quadrupole lens. Then, by laser-induced fluorescence , the hyperfine spectra of both the isotopes were recorded together with the laser parallel and anti-parallel with the ion beam. The differential Doppler shift was determined from the frequency separation of any two lines (each belonging to one isotope) in the combined hyperfine spectra in the parallel and anti-parallel configuration.

4. RESULTS :

The combined laser-induced hyperfine spectra for the optical transition between $4f^7(^8S^0)5d\ ^9D_4{}^0$ and $4f^7(^8S_{7/2}{}^0)6p_{3/2};J'=4$ at a wavelength 604.951 nm for both the isotopes recorded in the parallel and anti-parallel geometries are shown in Fig.1 and Fig.2, respectively. The centers of gravity of the hyperfine structure and the transitions are indicated in the figures. The isotope shift for four optical transitions between the metastable states $4f^7(^8S^0)5d\ ^9D_J^0$ and the state $4f^7(^8S_{7/2}^0)6p_{3/2};J'$ are given in Table I. Also the isotope shift measurement of Dörschell et al [5] for the transition at wavelength 604.951 nm has been given for comparison. An analysis of these measurements to obtain some nuclear properties will appear elsewhere.

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TABLE I

Isotope Shift in $^{151,153}Eu^+$

Optical Transition	Transition Wavelength (nm)	Isotope Shift	Reference (MHz)
$^9D_2^0 \leftrightarrow 6p_{3/2};J'=2$	581.874	1538.5(4.9)	This work
$^9D_3^0 \leftrightarrow 6p_{3/2};J'=4$	596.607	1476.2(4.8)	This work
$^9D_4^0 \leftrightarrow 6p_{3/2};J'=4$	604.951	1463.3(4.9)	This work
$^9D_4^0 \leftrightarrow 6p_{3/2};J'=4$	604.951	1467(10)	Dörschell et al. (1983)
$^9D_5^0 \leftrightarrow 6p_{3/2};J'=4$	617.305	1441.6(4.6)	This work

Figure Captions :

Fig. 1. Laser-induced fluorescence spectra of Eu^+ for the optical transition $^9D_4{}^0 \leftrightarrow 6p_{3/2};J'=4$ at wavelength 604.951 nm when both the isotopes are present in the ion beam, with the laser propagating parallel to the ion beam. The hyperfine transitions and the centers of gravity of the spectra for each isotope are also indicated.

Fig. 2. Same as in Fig.1 except for the laser propagating anti-parallel to the ion beam.

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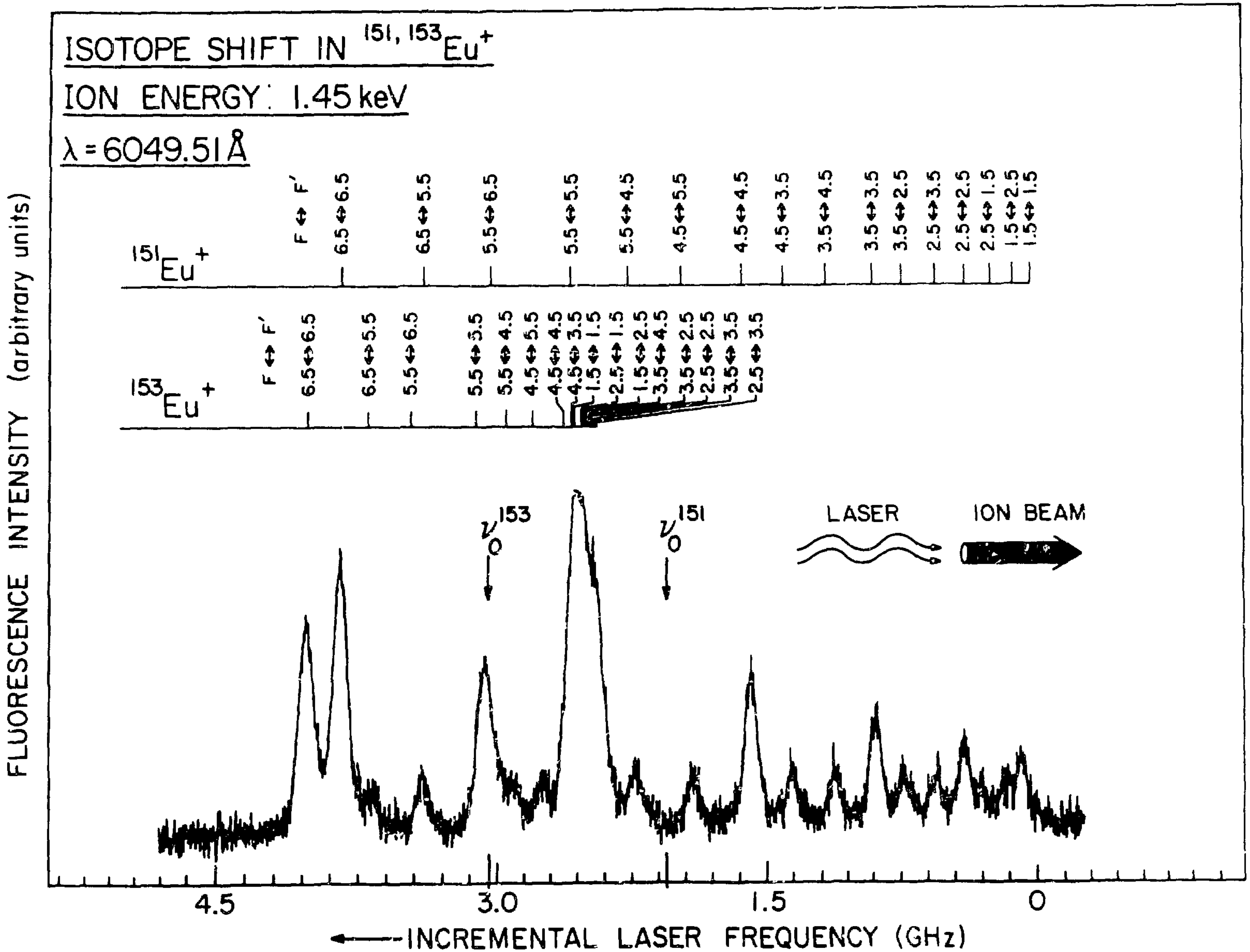

Fig. 1

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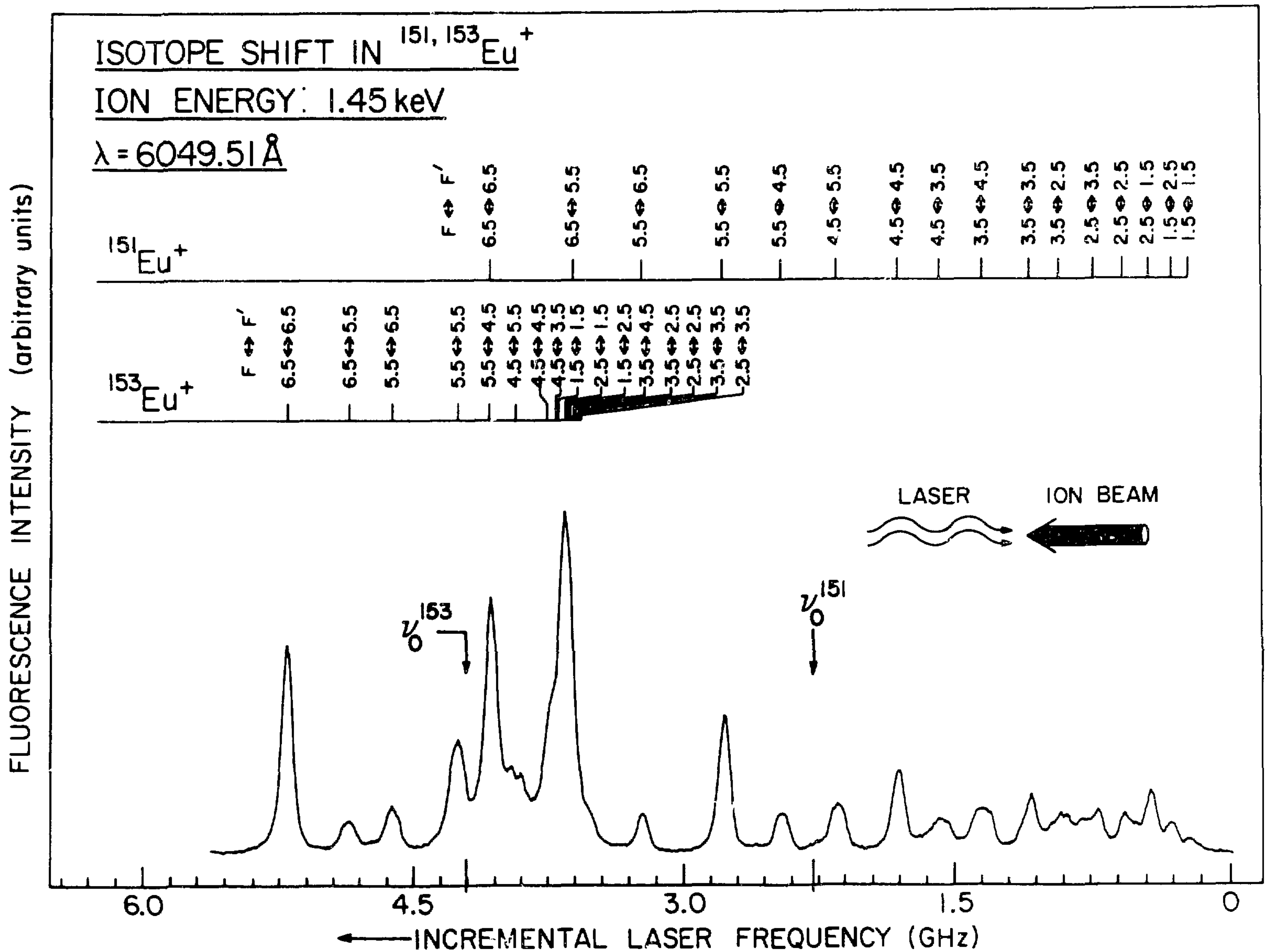

ISOTOPE SHIFT IN $^{151,153}Eu^+$
ION ENERGY: 1.45 keV
$\lambda = 6049.51$ Å
$^{151}Eu^+$
F ⇔ F′
6.5⇔6.5
6.5⇔5.5
5.5⇔6.5
5.5⇔5.5
5.5⇔4.5
4.5⇔5.5
4.5⇔4.5
4.5⇔3.5
3.5⇔4.5
3.5⇔3.5
3.5⇔2.5
2.5⇔3.5
2.5⇔2.5
2.5⇔1.5
1.5⇔2.5
1.5⇔1.5
$^{153}Eu^+$
F ⇔ F′
6.5⇔6.5
6.5⇔5.5
5.5⇔6.5
5.5⇔5.5
5.5⇔4.5
4.5⇔5.5
4.5⇔4.5
4.5⇔3.5
1.5⇔1.5
2.5⇔1.5
1.5⇔2.5
3.5⇔4.5
3.5⇔2.5
2.5⇔2.5
3.5⇔3.5
2.5⇔3.5
LASER
ION BEAM
ν_0^{153}
ν_0^{151}
FLUORESCENCE INTENSITY (arbitrary units)
6.0
4.5
3.0
1.5
0
← INCREMENTAL LASER FREQUENCY (GHz)