объединенный
институт
ядерных
исследований
дубна

E6-92-319

A.Anastassov, Yu.P.Gangrsky, B.K.Kul´djanov [1],
K.Marinova [2], B.N.Markov, E.Nadjakov [2]
S.G.Zemlyanoi

HYPERFINE SPLITTING CONSTANTS OF THE a^3F_3 AND $z^5G^0_3$ HfI LEVELS

Submitted to "Zeitschrift für Physik, Section D, Rapid Notes"

[1] Institute of Nuclear Physics, Uzbek Academy of Sciences, 702132 Ulughbek, Tashkent, Uzbekistan
[2] Department of Physics, University of Sofia, Baucher St.5, 1126 Sofia, Bulgaria

1992

1. INTRODUCTION

At the Laboratory of Nuclear Reactions (JINR), laser-spectroscopic measurements for the determination of the changes in the mean-square nuclear charge radii of hafnium isotopes have been performed /1/. In these experiments, the hyperfine splitting (hfs) constants of the lower and the upper levels of the transition investigated have been determined.

Excitation on the transition $5d^2 6s^2\ a^3F_3$ (2356.68 cm^{-1})$\rightarrow$ $5d^2 6s6p\ z^5G^o_3$ (19292.69 cm^{-1}) was used (the data are from the tables of Moore /2/). The lower level belongs to the HfI ground term and no information on its hfs was available up to now. Only the hfs constants of the ground state a^3F_2 have been determined by Büttgenbach et al. /3/ with the help of the high accuracy ABMR technique. As for the upper $z^5G^o_3$ level, there are preliminary results /4/ on A and B values only for ^{177}Hf. The present measurements improve the accuracy for the upper transition level in the case of ^{177}Hf and provide new information in all other cases.

2. EXPERIMENTAL

The experimental method used in the present work is based on the detection of the laser excited fluorescence in a well collimated atomic beam.

The 5145 Å single line output of an Ar^+-laser (Spectra Physics) pumps the tunable cw ring dye-laser (SP -380D). The dye-laser output intersects orthogonally a collimated atomic beam and the resonance fluorescence is detected by a photomultiplier operating in the single photon counting mode. The spectra are recorded by a multichannel analyzer as a function of the dye-laser frequency. In order to obtain accurate determination of peak separations a confocal Fabry-Perot interferometer (free spectral range 150 MHz) was used to produce a set of frequency markers recorded simultaneously with the optical spectra. The spectrometer is described in details elsewhere (e.g. /5/).

Hafnium is one of the highly refractory elements. We have found out that the best way to vaporize Hf and form an atomic beam is to apply laser evaporation. For this purpose, a Q-switched Nd:YAG laser (λ=1.06 μm, pulse duration τ=10 ns, max. energy in a pulse E=50 mJ, repetition rate 12.5÷100 Hz) was used /6/ . A synchronization between the laser pulses and the registration system ensured photon counting only when an atomic bunch was in the interaction region. In our experiments metallic Hf of natural abundance as well as HfO_2 samples were used and in both cases a steady evaporation with sufficiently high yield of neutral atoms was obtained.

In order to reduce the background from the scattered laser light, the spontaneous decay to the ground state $5d^2 6s^2\ a^3F_2$ was detected. The registered linewidth (FWHM) of 45 MHz is determined by the Doppler broadening (the linewidth of the dye-laser output is about 3 MHz).

Measurements with enriched HfO_2 samples (82% ^{177}Hf) allowed to resolve very well at least seven hfs components (see Fig.1). The total splitting of the spectrum was obtained to be nearly 2.3 GHz. Then the components belonging to ^{179}Hf could be identified from the spectra of natural abundance metallic Hf, though there is a considerable overlapping. The total hfs splitting in this case is about 2.8 GHz.

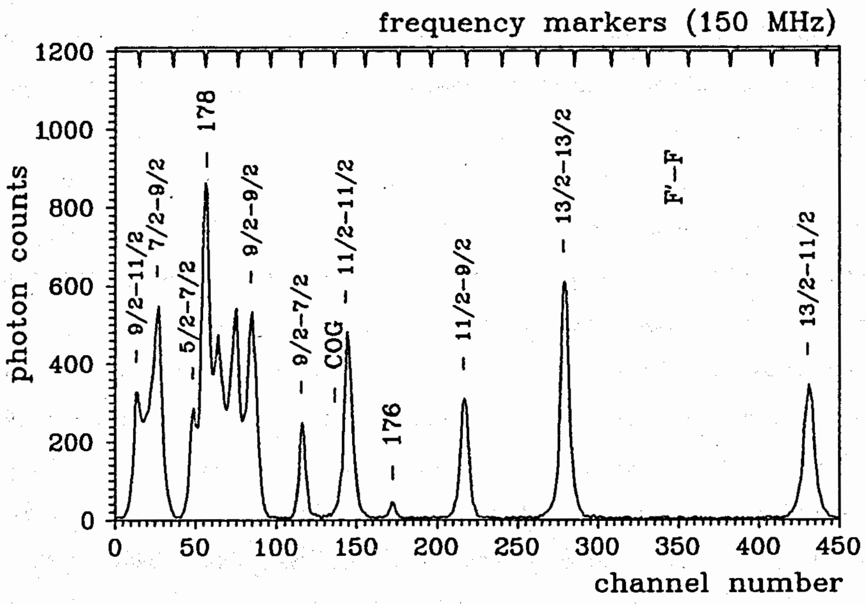

Fig.1. *Hfs spectrum of* ^{177}Hf *at the optical transition 5903* Å. *The identification of some hyperfine structure components is also shown: F' and F denote the total angular momentum of the upper and lower transition levels, respectively.*

3. RESULTS

For the identification of the hfs components and for the evaluation of the magnetic dipole and electric quadrupole hfs constants A and B, a least-square fit program combined with statistical χ^2-test to reject the incorrect assignment was used. The hfs of the investigated transition has the following features:

1) ^{177}Hf has a nuclear spin $I=7/2$, therefore the upper and lower atomic levels (having equal J) split into seven hyperfine sublevels with total angular momenta F from 1/2 to 13/2. This leads to nineteen hfs components in the optical spectrum.

2) The nuclear spin of ^{179}Hf is $I=9/2$ and the atomic levels under investigation also split into seven hfs sublevels with F

from 3/2 to 15/2, i.e. there are nineteen hfs components of the optical transition. This case is more complicated, because no data on A and B for the investigated levels are available. As a first order approximation in the evaluation of the hfs constants we made use of the fact that the ratios of the A-values as well as the ratios of the B-values for the upper and lower levels are nearly equal for different isotopes of a given element.

Table 1 summarizes the obtained results. The ratios of the hfs constants for the two stable odd Hf isotopes, $A(177)/A(179)$ and $B(177)/B(179)$, are also presented.

LEVEL, cm^{-1}	2356.68 (a^3F_3)	19292.69 ($z^5G^o_3$)	
^{177}Hf A, MHz	81.03 (29)	152.2 (4)	
B, MHz	800.3 (5.8)	1821.6 (7.4)	
^{179}Hf A, MHz	-50.8 (2)	-95.5 (1.1)	
B, MHz	903.0 (7.0)	2055.7 (25.1)	
$A(177)/A(179)$	-1.595 (8)	-1.594 (18)	-1.5880*
$B(177)/B(179)$	0.886 (9)	0.886 (11)	0.8849*

Table 1. *Results on the hfs constants A and B of the investigated levels and their ratios for* ^{177}Hf *and* ^{179}Hf. *Values marked with *) are taken from /3/.*

A comparison with the corresponding high-accuracy values for these ratios from /3/(see Table 1) shows a good agreement. The slight discrepancies observed could be ascribed to two reasons: *i.* the experimental method used in the present work is less accurate than ABMR, *ii.* higher order multipole interactions are not taken into account.

The frequency shifts of the hfs centers of gravity with respect to the ^{178}Hf peak are $\nu_{cog}(179)-\nu(178)=-379.1(4.1)$ MHz, $\nu_{cog}(177)-\nu(178)=614.8(8)$ MHz.

REFERENCES

1. Anastassov, A., Gangrsky, Yu.P., Kul'djanov, B.K., Marinova, K., Markov, B.N., Zemlyanoi, S.G.: In: Penionzhkevich, Yu.E., Kalpakchieva, R. (eds.): Exotic Nuclei, Proc. Int. Conf., Crimea, 1991. Singapore: World Scientific 1992

2. Moore, C.E.: Atomic Energy Levels III. Washington: National Bureau of Standards 1958

3. Büttgenbach, S., Herschel, M., Meisel, G., Schödl, E., Witte, W.: Z.Phys. 260, 157 (1973)

4. Baumann, P., Kuszner D., Nunnemann, A., Zanger, E., Zimmermann, D.: In: de Vries, A.E., van der Wiel, M.J. (eds.): 2nd ECAMP Book of Abstracts, p. 13. Amsterdam: Free University 1985

5. Gangrsky, Yu.P., Marinova, K.P., Markov, B.N., Nadjakov, E.G., Oganessian, Yu.Tz., Han Gyong I, Tran Cong Tam: Izv. Acad. Nauk USSR, Ser. Fiz. **49**, 2261 (1985)

6. Gangrsky, Yu.P., Zemlyanoi, S.G., Kul'djanov, B.K., Marinova, K.P., Markov, B.N., Hoang Thi Kim Hue, Chan Kong Tam: Sov. Phys. JETP **67**, 1089 (1988)

Received by Publishing Department
on July 22, 1992.

Анастасов А. и др. Е6-92-319
Константы сверхтонкого расщепления
уровней нейтрального гафния a^3F_3 и $z^5G^0_3$

Методом лазерной спектроскопии высокого разрешения проведены исследования сверхтонкой структуры и изотопических сдвигов для оптического перехода в HfI с длиной волны 5903 Å. Определены магнитная дипольная и электрическая квадрупольная константы сверхтонкого расщепления нижнего $5d^26s^2$ a^3F_3 и верхнего $5d^26s6p$ $z^5G^0_3$ уровней для двух стабильных нечетных изотопов ^{177}Hf и ^{179}Hf.

Работа выполнена в Лаборатории ядерных реакций ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1992

Anastassov A et al. E6-92-319
Hyperfine Splitting Constants
of the a^3F_3 and $z^5G^0_3$ HfI Levels

The hyperfine structure and the isotope shifts in the optical transition of HfI with λ = 5903 Å have been investigated using high resolution laser spectroscopy. The magnetic dipole and electric quadrupole hyperfine splitting constants of the lower $5d^26s^2$ a^3F_3 and upper $5d^26s6p$ $z^5G^0_3$ levels have been determined for the two stable odd hafnium isotopes ^{177}Hf and ^{179}Hf.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1992