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MEASUREMENT OF THE HYPERFINE STRUCTURE OF OPTICALLY EXCITED STATES OF RADIOACTIVE ISOTOPES

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May 23, 1967

MEASUREMENT OF THE HYPERFINE STRUCTURE OF OPTICALLY EXCITED STATES OF RADIOACTIVE ISOTOPES*

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Of the methods currently available for the study of hyperfine structure (hfs) in optically excited states, none is generally suitable for the study of radioactive isotopes. Optical double resonance, level-crossing spectroscopy conventional optical spectroscopy, and other techniques where the light is detected are not suitable for studying trace amounts of radioactive isotopes in the presence of large amounts of stable carrier. Moreover, wall interaction interferes with attempts to study separated samples. An atomic-beam experiment was devised by Perl, Rabi, and Senitzky for studying the excited states of the alkalis by direct magnetic resonance.[1] However, this method cannot be easily generalized to radioactive isotopes because of the small signals involved.

It has been shown recently[2] that the atomic-beam method can be extended to the study of isotope shifts and the optical Stark effect in radioactive isotopes. In this letter we describe a way this method can be modified to obtain a substantial improvement in resolution. With this improvement, details of the hfs of the $6^2P_{1/2}$ states of the cesium isotopes are revealed to a precision of about 50 MHz. It is felt that this method should be generally applicable to the study of the hfs of optically excited states in any isotope (radio-

active or stable) that can be deflected in an atomic-beam apparatus, and we report here as a demonstration the measurement of the hfs in the $6^2p_{1/2}$ state of $^{134m}Cs(\tau_{1/2} = 2.9\ h)$.

The basic apparatus (see Fig. 1) is identical to that of Ref. 2 except for the addition of an atomic-beam absorption cell. An atomic beam flop-in apparatus is employed whose C region consists of a pair of electric field plates with a gap of 0.035 in. The plates consist of a heated-glass cathode and a stainless steel anode both of which are ground to within 10^{-4} in. The homogeneity of the electric field produced is estimated to be about 0.5% and is sufficiently good so that it does not contribute appreciably to the line width. Light from a cesium-resonance lamp illuminates the region in the gap. The light is filtered so that only the D_1 transition ($6^2p_{1/2} \rightarrow 6^2s_{1/2}$) is passed. In the lamp line, the hfs of the $6^2p_{1/2}$ state is not completely resolved and the lamp line consists of a doublet, the components of which are separated by the hfs of the ground state. With this apparatus, the precision is limited by the width of the lamp line, about 1500 MHz. However, the precision may be substantially improved by passing the filtered light through an optically dense cesium absorption beam. The effect of the absorption beam is to remove from each of the lamp lines a doublet. The two components of the doublet are separated by the hfs of the $6^2p_{1/2}$ state, and each component has a width of about 150 MHz (see the energy-level diagram in Fig. 2). In principle, this width can be made as low as the natural line width, which for the cesium resonance line is about 10 MHz. However, such high precision would demand an electric field that is homogeneous and reproducible to better than 0.5×10^{-3} at fields of

almost 0.5×10^6 volts/cm. This is presently beyond our capability and accordingly we have designed our absorption beam to achieve a width of about 150 MHz.

The Cs atoms in the atomic-beam apparatus are state-selected by the narrow gap between the electric-field plates so that essentially we can refocus only atoms in the lowest hyperfine state ($F = 3$ for ^{133}Cs and $F = 15/2$ for ^{134m}Cs). The observed ^{133}Cs intensity pattern is shown in Fig. 2 and can be understood with reference to the inserted energy-level diagram. Indicated directly above each of the observed intensity minima is the position of the Stark-shifted energy levels of ^{133}Cs beam atoms relative to the unshifted levels of atoms in the absorption cell. At zero electric field the absorption lines of the Cs atomic beam overlap the absorption lines of the Cs absorption beam, and a minimum in the intensity curve is observed. However, as the electric field is turned on, the Stark effect decreases the frequency of the absorption lines of the atoms in the beam apparatus, and the observed signal increases. However, when the electric field is sufficient to shift the frequency by an amount equal to the hfs of the <u>excited</u> ($6^2P_{1/2}$) state, a second intensity <u>minimum</u> is observed. At higher electric fields the frequency is shifted by an amount equal to the ground-state hfs, and the beam-absorption line is brought into resonance with the second lamp-emission line. Here three intensity minima can be observed corresponding to the overlap positions indicated in the energy-level diagram. These three minima are equally spaced and correspond to a shift by an amount equal to the hfs of $6^2P_{1/2}$. The unlabelled minima correspond to structure present in the lamp line.

As can be seen from the energy-level diagram, the separation between the two minimum points labeled α and δ corresponds to a Stark shift of the energy levels equal to 9192 MHz, the hfs of the ^{133}Cs ground state. Using this as a calibration, and taking the separations α-β, γ-δ, δ-ϵ as equal to the hfs of the $6^2p_{1/2}$ state, we obtain

$$\Delta\nu^{133}(6^2p_{1/2}) = 1167 \pm 40 \text{ MHz}.$$

This value is in good agreement with the value obtained by conventional optical spectroscopy.[3]

A similar situation pertains when the atomic beam consists of radioactive ^{134m}Cs. Here, however, the hfs of both $6^2s_{1/2}$ and $6^2p_{1/2}$ are smaller than for ^{133}Cs, so that Stark tuning can bring about only one overlap of the beam absorption lines with the lamp emission lines. However, there are four possible overlap positions of the Stark-shifted energy levels of ^{134m}Cs beam atoms with the unshifted levels of ^{133}Cs atoms in the absorption cell. As seen in Fig. 3 these overlap positions correspond to minima in the observed intensity pattern. From the energy-level diagram it is clear that the separation between the minima α and β and between γ and δ corresponds to the hfs of the $6^2p_{1/2}$ state of ^{134m}Cs. These are experimentally seen to be equal. Moreover, the separations between α and γ and between β and δ should correspond to the hfs of the $6^2p_{1/2}$ state of ^{133}Cs. This also agrees with our observations. From the observed separations we infer

$$\Delta\nu^{134m}(6^2p_{1/2}) = 473 \pm 60 \text{ MHz}.$$

In addition, from the position of the minima we obtain a new precision value for the ^{134m}Cs–^{133}Cs isotope shift (IS). We find

$$IS = +1.4(2.0) \times 10^{-3}\ cm^{-1},$$

where the positive sign indicates that the shift is in the direction predicted by the normal-volume effect. This value is substantially smaller than that reported in Ref. 2, where apparently an overly optimistic assessment of the error was made.

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*Work supported by the U. S. Atomic Energy Commission.

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FIGURE LEGENDS

Fig. 1. Schematic diagram of apparatus.

Fig. 2. Observed ^{133}Cs signal vs (applied voltage)^2. The position of the Stark-shifted absorption lines relative to those in the absorption cell for each of the observed minima is indicated directly above the minima. The separation between α and δ corresponds to a shift equal to the ground-state hyperfine separation, and serves as a calibration.

Fig. 3. Observed ^{134m}Cs signal vs (applied voltage)^2. The minima α occurs when beam absorption line 1 coincides with ^{133}Cs absorption line A; β occurs when line 2 coincides with A; γ occurs when 1 coincides with B; and δ occurs when 2 coincides with B.

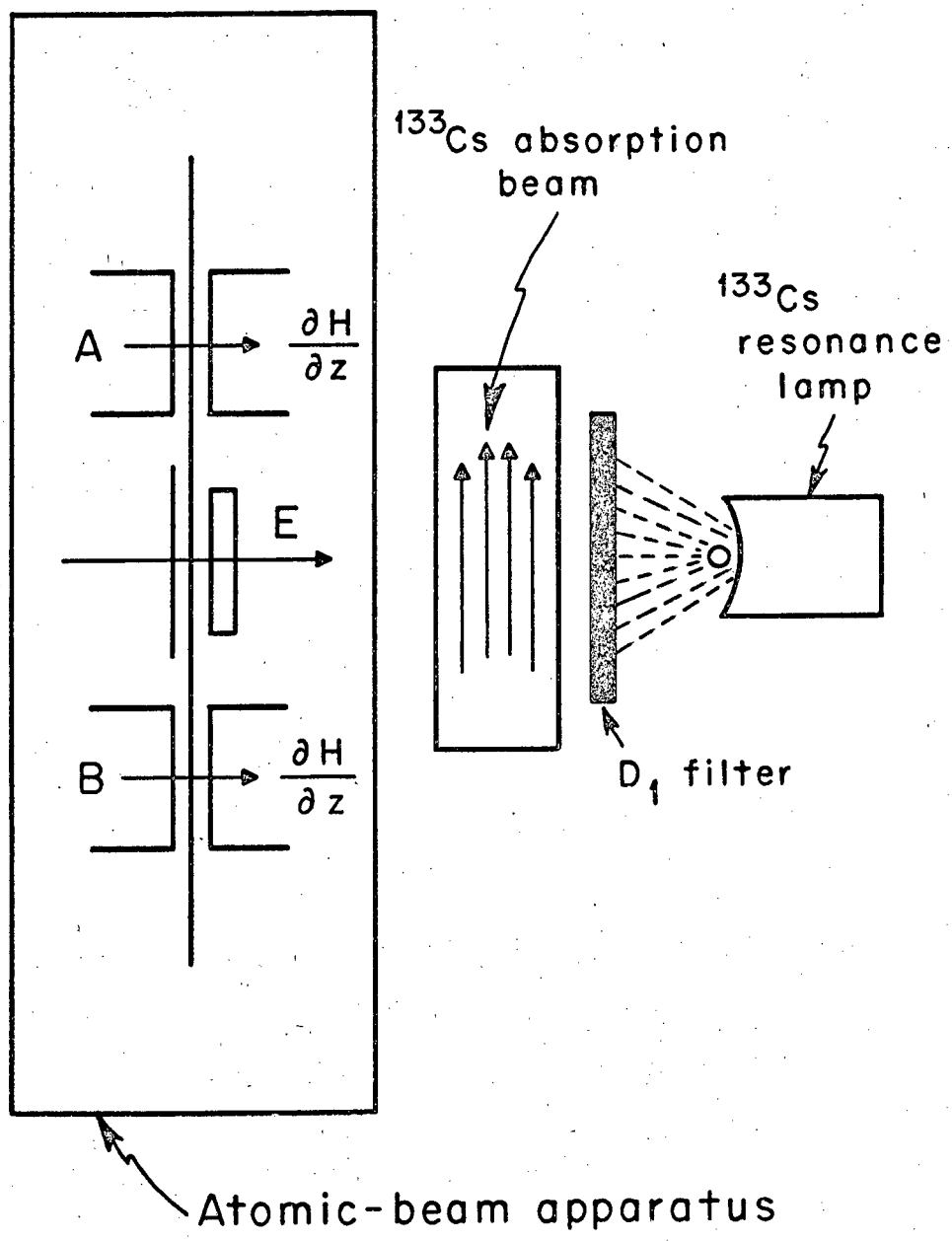

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Fig. 1

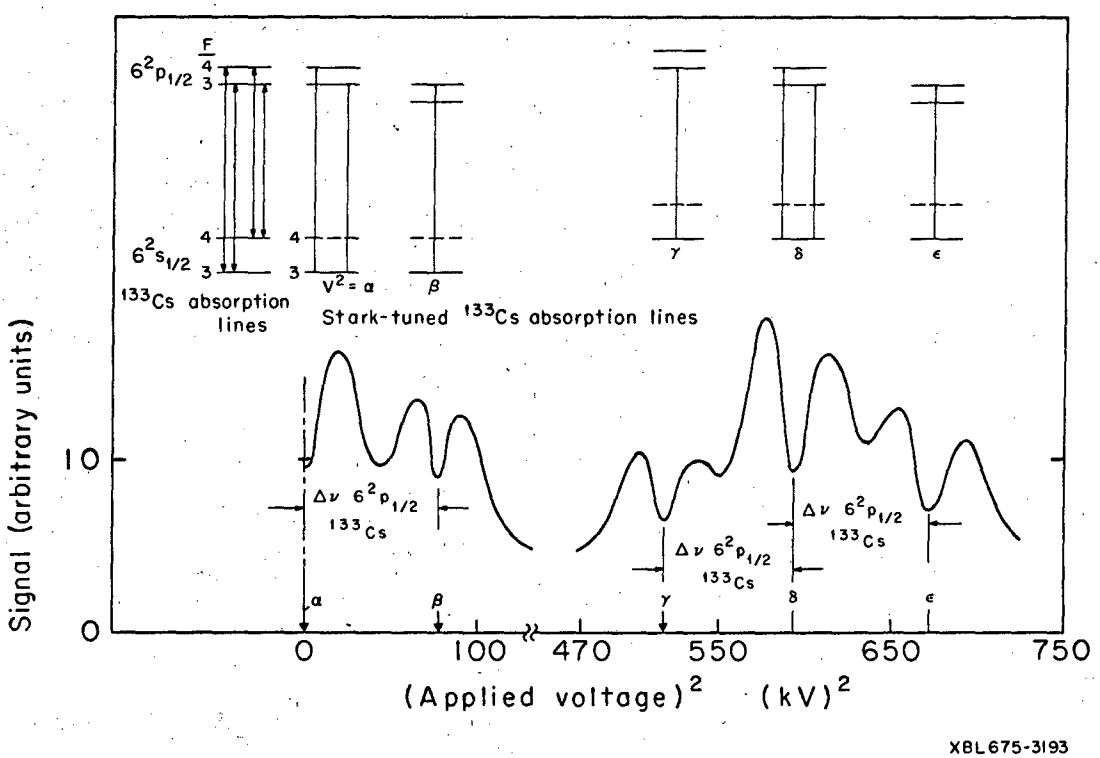
F
$6^2P_{1/2}$
4
3
$6^2S_{1/2}$
4
3
^{133}Cs absorption lines
$V^2 = \alpha$
β
γ
δ
ϵ
Stark-tuned ^{133}Cs absorption lines
Signal (arbitrary units)
10
0
$\Delta\nu$ $6^2P_{1/2}$ ^{133}Cs
$\Delta\nu$ $6^2P_{1/2}$ ^{133}Cs
$\Delta\nu$ $6^2P_{1/2}$ ^{133}Cs
α
β
γ
δ
ϵ
0
100
470
550
650
750
(Applied voltage)^2 (kV)^2
XBL675-3193

Fig. 2

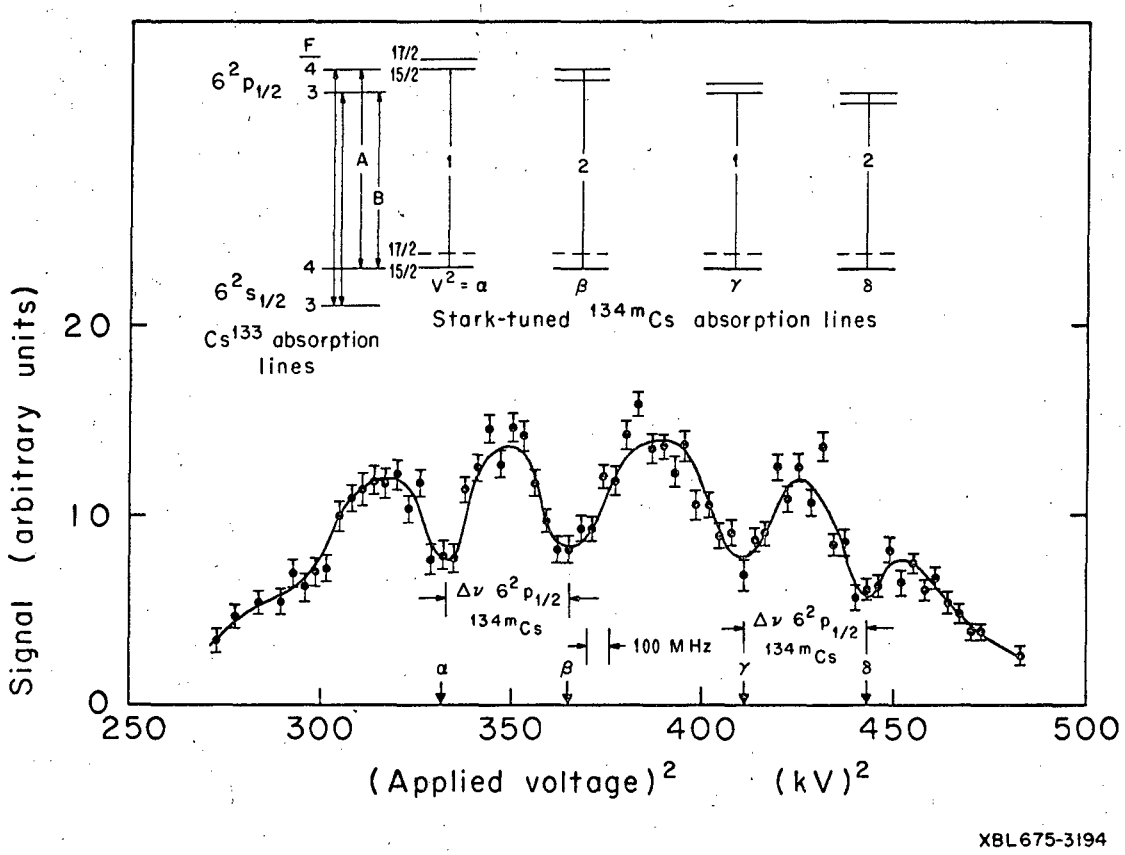

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Fig. 3

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