Lawrence Berkeley National Laboratory
Recent Work

Title
ATOMIC BEAM METHOD FOR THE STUDY OF ISOTOPE SHIFTS

Permalink
https://escholarship.org/uc/item/16w203vx

Authors
Marrus, Richard
McColm, Douglas.

Publication Date
1965-10-26

eScholarship.org Powered by the California Digital Library
University of California

University of California

Ernest O. Lawrence Radiation Laboratory

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

ATOMIC BEAM METHOD FOR THE STUDY OF ISOTOPE SHIFTS

Berkeley, California

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

To be submitted to Physical Review Letters

UCRL-16415

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

ATOMIC BEAM METHOD FOR THE STUDY OF ISOTOPE SHIFTS

Richard Marrus and Douglas McColm

October 26, 1965

ATOMIC BEAM METHOD FOR THE STUDY OF ISOTOPE SHIFTS*

Richard Marrus and Douglas McColm

Lawrence Radiation Laboratory and Department of Physics
University of California, Berkeley, California

October 26, 1965

In this Letter a new method is described for the study of isotope shifts. This method, based on the atomic beam technique, has the considerable advantage over optical techniques that it can be applied to radioactive nuclei in the presence of large amounts of stable carrier. Therefore, it will make possible an extension of our knowledge of isotope shifts to the large class of radioactive nuclei which can not be practicably studied by any currently existing techniques. As a demonstration we report here the application of this method to a measurement of the ^{133}Cs-^{134m}Cs (2.9 h) isotope shift in the $6^2P_{1/2} - 6^2S_{1/2}$ transition (D_1 line).

The basic apparatus employed is a conventional atomic beam apparatus with flop-in magnet geometry.[1] However, the C region consists of a pair of electric field plates capable of sustaining very large electric fields. The region between the plates is illuminated with D_1 radiation from a filtered lamp of stable ^{133}Cs. The lamp employed is a Varian X49-609 spectral lamp. The output of this lamp is a resolved doublet separated by approximately the ground-state hyperfine structure (hfs). The excited-state hfs is about 10% of the ground-state hfs.[2] It makes no essential difference in the following discussion and is ignored. The energy levels giving rise to the doublet are shown schematically in Fig. 1.

Consider now the action of a cesium-133 atom in the atomic beam irradiated by the resonance radiation at zero electric field. Under this condition, the absorption lines of the beam atom coincide with the centers of the emission lines

of the lamp. Consequently, resonance absorption of photons takes place. In the subsequent decay, the spin-flip of half the cesium atoms occurs and a large flop-in signal is observed at the detector. As the electric field is turned on, the Stark effect shifts the center of the absorption lines to lower frequencies until resonant absorption no longer occurs, and the flop-in signal goes to zero. However, when the shift is equal to the ground-state hyperfine structure a new overlap of the absorption line with the emission line of the lamp occurs (see Fig. 1); and another flop-in signal is observed. In this way the Stark effect can be measured for the D_1 line; if the V^2 dependence characteristic of the Stark effect is assumed, a calibration of frequency shift vs applied voltage is obtained.

These same principles can be directly applied to the measurement of isotope shifts. Consider now a beam atom of some other cesium isotope. Because of the different ground-state hyperfine structure and the isotope shift there is, in general, no signal at zero field. However, if the energy of the absorption lines is displaced to the high-energy side of either of the emission lines of the lamp, then the application of a suitable voltage brings the absorption lines into coincidence with the emission lines and a signal is observed at the detector. If the hyperfine splitting is large compared to the emission width of the lamp ($\approx$ 1500 Mc),[3] then the hyperfine structure can be determined. The use of radioactive detection, which has been employed so successfully in the study of spins and moments, makes it possible to study rare radioactive isotopes.[4]

The spacing of the electric field plates used in our apparatus is sufficiently narrow (plate separation = 0.10 cm) that only the transition for which $m_J = -1/2$ in the A magnet and $m_J = +1/2$ in the B magnet is refocused. This precludes signals from the upper hyperfine level. Only signals resulting from atoms in the $F = 3$ state of ^{133}Cs and $F = 15/2$ state of ^{134m}Cs ($I = 8$) can be observed.

The flop-in signal for a ^{133}Cs beam as a function of applied voltage squared (V^2) is shown in Fig. 2. The signals at zero electric field and at 25 000

volts correspond to the absorption of the $F = 3$ and $F = 4$ hyperfine lines in the lamp by atoms in the $F = 3$ state in the beam. The separation between the peaks corresponds to the known hyperfine structure 9192 Mc. The half width of the peaks is about 1500 Mc, which agrees well with an independent measurement of the half width of the lamp emission line.[3]

Figure 3 is a graph of signal vs V^2 for a beam of ^{134m}Cs atoms. The presence of a single peak at 24.1 kilovolts establishes the zero-field positions of the ^{134m}Cs hyperfine levels to be as shown in Fig. 1 relative to the ^{133}Cs hfs. The energy of the D_1 transition in ^{134m}Cs is smaller than that in ^{133}Cs by 900 (350) Mc or 0.030 (.012) cm^{-1}, where the difference is taken between the centers of gravity of the hyperfine levels.

In this experiment we have chosen to use an electric field to "tune" the absorption lines of beam atoms. Similar optical resonance experiments have been performed which utilize magnetic fields for line tuning.[5] Electric fields have the advantage that to second order all the hyperfine components of a $J = 1/2$ level are shifted together; i.e., there is a displacement of only the center of gravity. Relative shifts of the hyperfine levels[6] and of their Zeeman components[7] are much smaller, and for the purpose of this experiment are entirely negligible. This makes for easily interpretable signals which are much larger in intensity than those which would be obtained with magnetic tuning. However, the Stark effect shifts the energy in one direction only, whereas magnetic tuning increases the energy of some transitions and decreases the energy of others. For some isotopes, therefore, only magnetic tuning will make possible isotope shift measurements.

An interesting way to regard this experiment is to think of the beam machine as a tuneable spectrometer for studying the emission profile of the lamp. Since the light is perpendicular to the beam direction, there is no Doppler effect and the resolution of the instrument is the natural line width of the transition--about 10 Mc for the cesium D_1 line[8] but perhaps much less for other transitions. We are currently investigating the ultimate sensitivity and the useful frequency range for an atomic beam apparatus used in this way.

It is a pleasure to acknowledge the invaluable advice of Dr. Joseph J. Murray of the Lawrence Radiation Laboratory staff concerning the design of the electric field plates.

REFERENCES

*This research was supported by the U. S. Atomic Energy Commission.

1. J. R. Zacharias, Phys. Rev. 61, 270 (1942).
2. H. Kleiman, J. Opt. Soc. Am. 52, 441 (1962).
3. We thank Dr. R. McLaughlin of the Lawrence Radiation Laboratory for providing us with a lamp profile obtained from a densitometer trace.
4. For a review, see W. A. Nierenberg, Ann. Rev. Nucl. Sci. 7, 349 (1957).
5. O. Buhl, Z. Physik 109, 180 (1938) and 110, 395 (1938); F. Bitter, S. P. Davis, B. Richter, and J. Young, Phys. Rev. 96, 1531 (1954).
6. R. D. Haun, Jr., and J. R. Zacharias, Phys. Rev. 107, 107 (1957).
7. P. G. H. Sandars and E. Lipworth, Phys. Rev. Letters 13, 716 (1964).
8. A. C. G. Mitchell and M. W. Zemansky, Resonance Radiation and Excited Atoms (Cambridge University Press, 1961), p. 146.

FIGURE CAPTIONS

Fig. 1. Energy level diagram. The lines labeled A and B are both present in the lamp. At zero applied voltage, the energy of the transition labeled 1 is in resonance with the emission line B and a flop-in signal is observed. At 32 kV, transition 1 now resonates with the emission line A. Our apparatus geometry precludes the observation of signals from the $F = 4$ state.

Fig. 2. Observed signal vs (applied voltage)^2 for a cesium-133 beam.

Fig. 3. Observed signal vs (applied voltage)^2 for a cesium-134m beam.

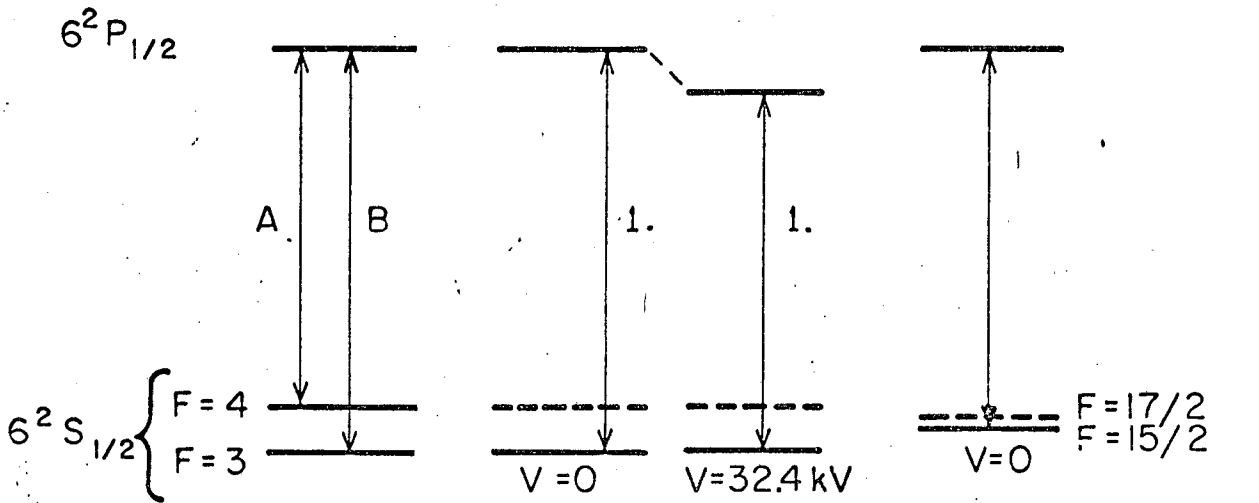


Fig. 1

MUB-8469

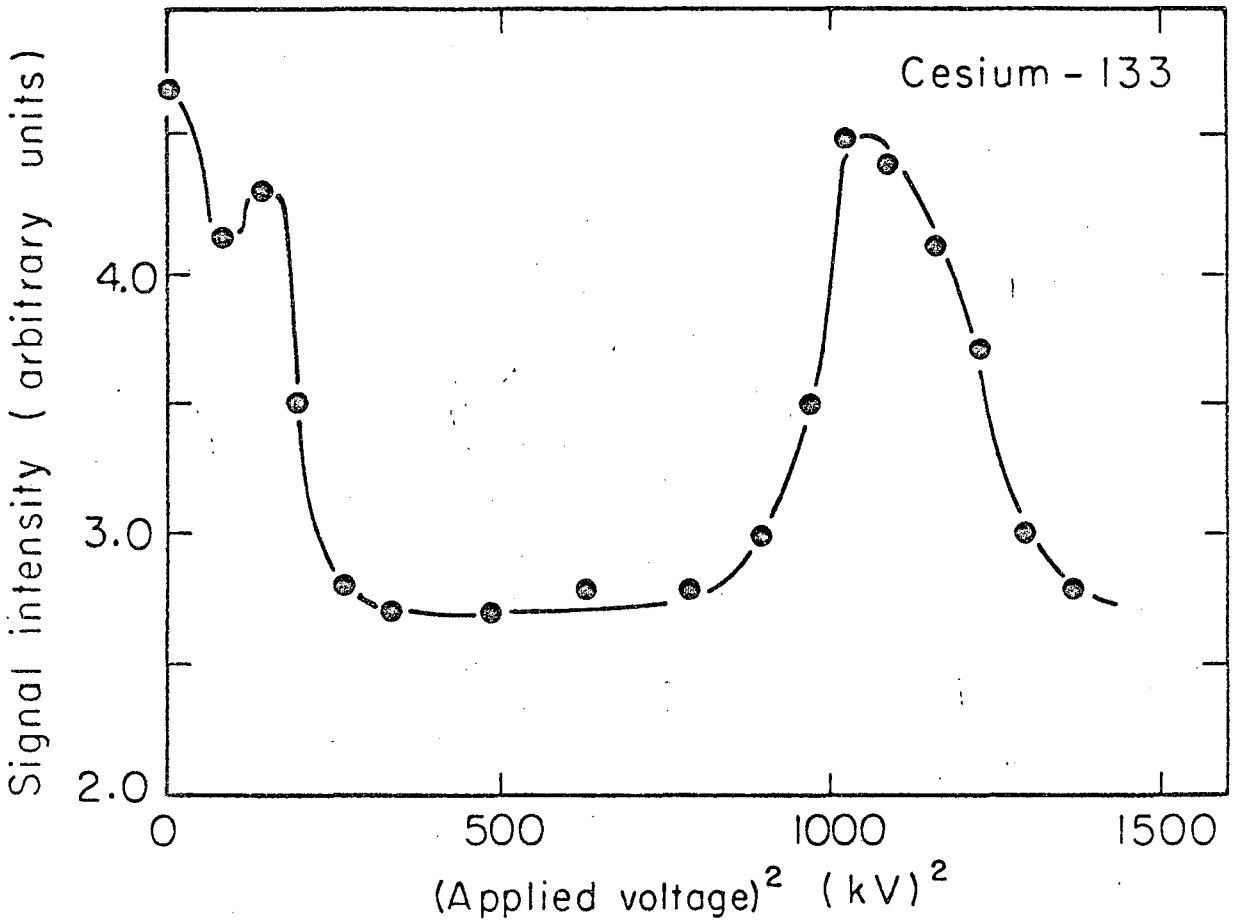
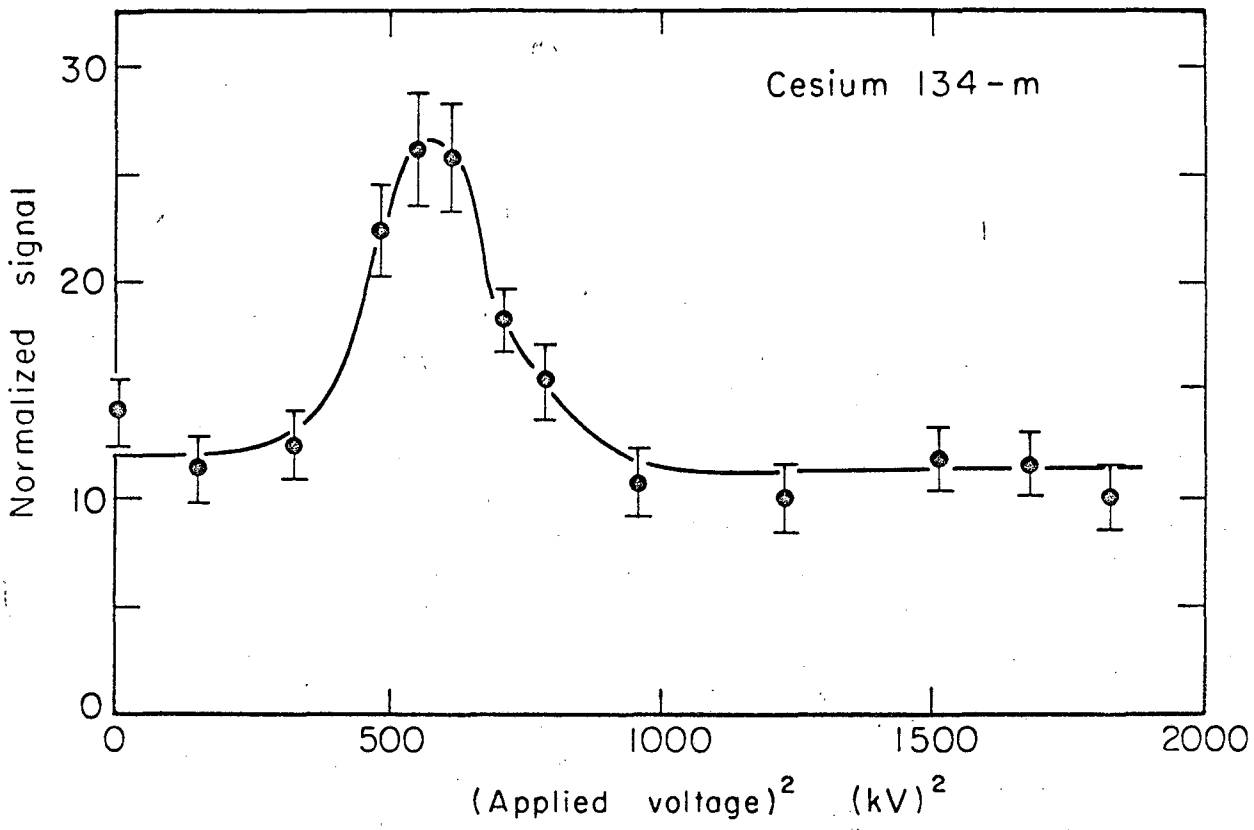


Fig. 2

MUB-8470



MUB-8471

Fig. 3

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.