THE MEASUREMENT OF E2 AND E4 MOMENTS USING EXOTIC ATOMS

R. J. POWERS
California Institute of Technology, Pasadena, California

Recent developments in the determination of quadrupole and hexadecapole moments of nuclear distributions using the exotic atom technique are discussed. As an indication of the sensitivity of muonic data to higher charge moments, I concentrate the discussion on recent work in highly deformed nuclei. Using the hyperfine structure (h.f.s.) of the muonic 3d state it is not difficult to obtain 1% accuracy for the static E2 moment of the ground state. Typically 40% accuracy can be ascribed to E4 moment determinations. The 2p h.f.s., on the other hand, can be used to determine the static moments of excited states as well as the dynamic moments (or BE2's) connecting these states with the ground state. Combining this information with radial charge parameter information from the absolute transition energies of the 2p → 1s(K) and 3d → 2p(L) transitions allows one to study the distribution of the E2 density.

The question of obtaining complementary nuclear matter deformation from pionic atoms is discussed.

1. INTRODUCTION

The use of exotic atom hyperfine structure as a means of studying nuclear deformations began nearly fifteen years ago. However, experimental physicists had to wait until the development of solid-state detectors, before they could produce results with an accuracy comparable to standard spectroscopic methods using this technique. Today the steady evolution of improved detectors and more intense muon and pion beams allow the determination of quadrupole (hexadecapole) moments of strongly deformed nuclei to better than 1% (40%).

There are basically two reasons which make this technique so powerful in determining nuclear deformations. First since one is dealing with hydrogen-like atomic systems, the x-ray spectra of exotic atoms are, in general, more amenable to interpretation in terms of static nuclear moments than are normal spectroscopic methods. Indeed it has been often suggested that muonic atoms be used to check field gradient and shielding effect calculations necessary to interpret normal atomic h.f.s. A discussion of the use of exotic atoms for "calibrating" E2 hyperfine interactions in normal atoms can be found in the proceedings of the last

* Work supported by the Energy Research and Development Administration.
meeting in this series of conferences on h.f.s. Secondly the fact that the "heavy electron" binding energies of exotic atoms are scaled up by the mass of the particle orbiting the nucleus makes the excitation of the nucleus during the atomic cascade a fairly common occurrence particularly in the case of muonic atoms of strongly deformed nuclei. As a result it is not unusual to be able to determine not only the ground static moments but also the static moments of excited nuclear states and the dynamic moments associated with the E2 nuclear excitation. This allows the muonic atom to bridge the gap between spectroscopic methods of determining static moments and dynamic methods such as Coulomb excitation for studying nuclear deformations. This latter capability is particularly interesting for studying the ratios of quadrupole moments as a test of nuclear models particularly in those regions of the periodic table such as the transition regions between strongly deformed and spherical nuclei where nuclear models are not well established.

In this discussion I propose to concentrate on that work in exotic atom h.f.s. which has taken place since the compilation of muonic atomic data by Engfer et al.\textsuperscript{4} two and a half years ago. After a brief review of the elements of muonic atom electric h.f.s. in order to give you a feel for the magnitude of observables involved, I plan to present recent data from selected isotopes to indicate the sensitivity of this technique. In particular I will discuss $^{161}\text{Dy}$, a strongly deformed nucleus, where E2 effects are particularly large and excitation of the nucleus by the muon quite common. The fact that the rotational model is well accepted as a reasonable description of this isotope serves as a check of the validity of the muonic atom approach. Then we will consider the case of the almost spherical transitional nucleus $^{199}\text{Hg}$ which has spin ground state spin 1/2. In spite of the fact that this nucleus can have no ground state h.f.s. we shall see that excitation of the nuclei during the muon cascade allows us to determine the spectroscopic moments of the first two excited states and the BE2's connecting these states to the ground state. Such information is extremely important in testing nuclear models used to describe such transitional nuclei.

I will then briefly touch upon the sensitivity of muonic atom data to non-axially symmetric nuclear deformations and the complementary deformation information available from hadronic atoms. For the former I shall consider muonic $^{238}\text{U}$; for the latter, pionic $^{175}\text{Lu}$.

Finally I shall discuss the question of the experimental limitations of this technique as least as they exist today and the theoretical uncertainty involved in interpreting the data.

In the process of discussing the above features of exotic atom research, I hope to provide you with a necessarily superficial overview of what work is currently being carried out at various laboratories throughout the world.