# Proceedings of the VIII$^{th}$ International Symposium on NQR Spectroscopy

Darmstadt, July 22–26, 1985 · Z. Naturforsch. **41 a,** 1–462 (1986)

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We acknowledge the financial support of the following companies and organizations:

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Deutsche Forschungsgemeinschaft
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Stiftung Volkswagenwerk
The assistance of the Deutsche Bunsengesellschaft für Physikalische Chemie is acknowledged.

# Fifty Years of Nuclear Quadrupole Moments*

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Z. Naturforsch. **41 a**, 3–14 (1986); received September 14, 1985

On March 2, 1935 Hermann Schüler and Theodor Schmidt reported the first experimental evidence of non-spherical nuclei. From careful hyperfine structure studies of several Eu I-lines, they had shown that the hyperfine components of $^{151}$Eu and $^{153}$Eu did not follow the Landé interval rule exactly. Since the deviations were larger for $^{153}$Eu with the smaller magnetic moment, level perturbations were ruled out. This led to the conclusion of nuclear quadrupole moments. The theory was published June 1, 1935 by Hendrik B. G. Casimir. Nuclear deformations are playing a decisive role in modern nuclear structure physics. For solid state physics, spectroscopic quadrupole moments are very useful, since they probe the electric field gradient at the nuclei.

This review presents the discovery of 1935 in historical context: 1. Early measurements of nuclear radii. 2. Discovery of nuclear quadrupole moments. 3. Spectroscopic quadrupole moments (absolute measurements; relative hyperfine data, europium revisited). 4. Intrinsic quadrupole moments (discovery from isotope shifts; present status, samarium revisited). 5. Charge distribution of deformed nuclei.

## 1. Early Measurements of Nuclear Radii

75 years ago, on December 14, 1910, Ernest Rutherford wrote to a friend "I think I can devise an atom … [which] will account for the reflected $\alpha$ particles observed by Geiger" [1]. One of the most important experiments of this century had been known since May 1909, and was not understood at all. But that found little attention outside Manchester. There, in Rutherford's laboratory, Hans Geiger and Ernest Marsden had discovered and convincingly confirmed that $\alpha$ rays were backscattered from very thin metal foils [2]. Nearly two years after this surprizing discovery, on March 7, 1911, Rutherford presented his nuclear atom to the Manchester Literary and Philosophical Society [3] and Geiger stated at the same meeting [4] how he had experimentally verified the $1/\sin^4(\theta/2)$ dependence of large angle scattering calculated by Rutherford.

Geiger and Marsden then started with a new series of careful measurements which proved Rutherford's scattering law to be valid with respect to all parameters. Their results, published in July 1912 [5], gave the first experimental number for the extremely small radius of the nucleus: less than 30 fm in the case of gold.

Niels Bohr, whose 100$^{\text{th}}$ birthday the scientific world is celebrating this year, had moved to Manchester early in 1912. The first of his three famous papers "On the Constitution of Atoms and Molecules" is dated April 5, 1913. With the nuclear atom a new era for physics, chemistry, and all natural sciences had begun.

Already between 1915 and 1919, at least 12 geometric nuclear models – of course purely speculative – were proposed [6], all of them assuming electrons as constituents of the nucleus. Rutherford's desintegration of the nitrogen nucleus by $\alpha$ rays in 1919 gave the first evidence of nuclear structure [7]. In the same year he observed "anomalous results" for $\alpha$-p-scattering and concluded that the $\alpha$ particle was a disc with about 3 fm radius [8]. In 1924 Bieler [9] measured the deviation from point-nucleus scattering as a function of angle in ring geometry for aluminium and obtained 3.44 fm for its nuclear radius. But different analyses yielded substantially different values [10]. The sizes of the heaviest nuclei were evaluated in 1928 by Gamow and Houtermans [11]. They applied the theory of $\alpha$ decay to the Geiger-Nuttall-relation of 1911 [12].

In 1930, the well known $A^{1/3}$ rule was written down (for light nuclei) by Rutherford, Chadwick, and Ellis [13]: "For a rough approximation we may

* Presented at the VIIIth International Symposium on Nuclear Quadrupole Resonance Spectroscopy, Darmstadt, West Germany, July 22–26, 1985.

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0340-4811 / 86 / 0100-0003 $ 01.30/0. – Please order a reprint rather than making your own copy.