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THE DEPENDENCE OF RMS CHARGE RADII ON THE NEUTRON SKIN AND ON DEFORMATION

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The Dependence of RMS Charge Radii on the Neutron Skin and on Deformation†

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Current measurements of nuclear charge distributions are so accurate that extremely detailed comparisons are possible between experiment and microscopic theories such as Hartree-Fock calculations [1]. When the measured rms-radii of nuclei throughout the periodic table are compared with each other, and the result is plotted in a certain way [2,3], there seems to be evidence for significant shell effects. However, a closer look suggests that the rms-radii are predicted quite accurately by the Droplet Model (a macroscopic model that contains provisions for the possible formation of a neutrton skin)[4], if proper account is taken of the nuclear deformation.

Figures 1 and 2 (which are taken from [3] and [5] and can also be found in [2] along with a compilation of the primary data) show the structure in rms-radii that has recently attracted considerable interest. These figures are a little difficult to understand at first. In fig. 1 the quantity plotted is $\bar{A}_Z a_Z$ versus Z. The quantity a_Z is the slope ($\Delta\rho/\Delta N$) of a straight line drawn through the measured values of ρ = (rms - exp)/(rms - calc), where (rms - calc) = $\sqrt{3/5}\,(1.15 + 1.80A^{-2/3} - 1.20A^{-4/3})\,A^{1/3}$. (This expression for rms-calc gives good agreement for the variation of the rms-charge radius with A, for nuclei along the valley of beta-stability [6].)

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The quantities a_z are then multiplied by $\bar{A}_z$ (the average mass number for the isotopic sequence). In fig. 2 the same sort of presentation is made for the slope of the isotonic sequences versus the neutron number N.

The Droplet Model [4] predictions for the quantities $\bar{A}_z a_z$ and $\bar{A}_n a_n$ are given by the heavy, almost horizontal lines in figs. 1 and 2. In both cases the measured values and the Droplet Model agree when the corresponding isotopic (or isotonic) sequence is magic (and consequently free of deformation effects), as indicated by the numbers and arrows in the lower part of the figures. While it is true that the average trend in fig. 1 corresponds to an $A^{1/5}$ dependence for (rms - exp) [3], and the average trend in fig. 2 is close to an $A^{1/2}$ dependence [5], neither of these observations has any physical content.

The fact that the average trend in figs. 1 and 2 is given by the Droplet Model and the agreement is almost perfect when deformations are absent is associated with the existence of a "neutron skin" which is a feature of the model. Recognition of this agreement and a study of figs. 1 and 2 suggests that perhaps most of the remaining disagreement is associated with deformations.

To test this hypothesis, the deviation between the measured rms-charge radii tabulated in ref. [2] and the Droplet Model prediction were assumed to be due to a simple quadrupole deformation. Then the resulting quadrupole moment was compared with the measured value when it was available.

In fig. 3 Q_{exp} is plotted versus Q_{calc}. The fact that most of the points lie near the diagonal line ($Q_{exp} = Q_{calc}$) for deformed rare-earth nuclei supports our proposal. The deviation of the actinide points in the upper right corner may be due to the presence of hexadecapole deformations which were not taken into account.

There are probably also radial shell effects in the rms charge radius and perhaps effects due to large zero point quadrupole vibrations in nuclei that are not deformed, but are nonetheless soft against deformation [7]. Interesting effects such as these may show up if one looks closely at the remaining structure in the rms radius after first correcting for Droplet Model (neutron skin) and deformation effects.

Footnotes and References

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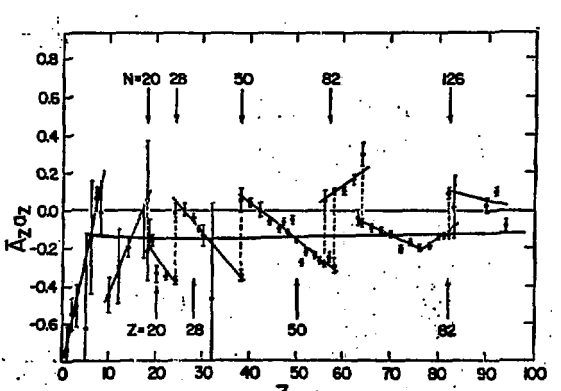

Fig. 1

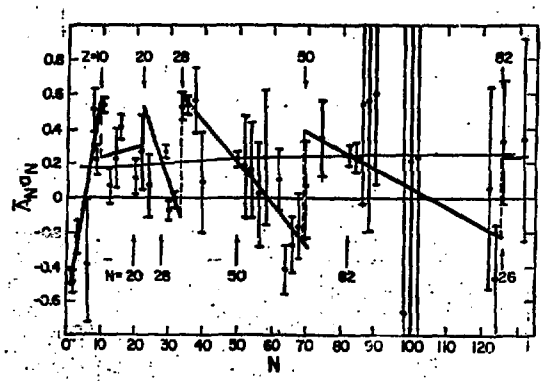
Z=10
20
28
50
82
N=20
28
50
82
126
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
10
20
30
40
50
60
70
80
90
100
110
120
N

Fig. 2

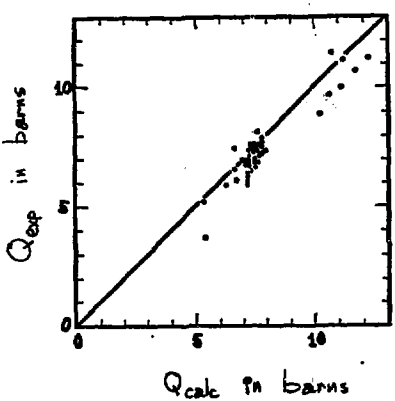
Q exp in barns
Q calc in barns
0
5
10
0
5
10

Fig. 3