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MANIFESTATION OF NON-TRADITIONAL MAGIC NUCLEON NUMBERS IN NUCLEAR CHARGE RADII

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Abstract

Using recent *rms* charge radius data, the neutron/proton number dependence of normalized radii is investigated along isotopic/isotonic series. The presence of non-traditional magic numbers can be observed in the region of light nuclei.

I. Introduction

The experimental methods (fast electron scattering, muonic atom *X*-rays, K_α isotope shift, optical isotope shift) yield information on the electric charge distribution in nuclei, and on its moment $R \equiv \langle r^2 \rangle^{1/2}$, the so-called root-mean-square (*rms*) charge radius. These quantities are determined by the charged protons. However, the distribution of protons is affected by the neutrons through the attractive *n*-*p* interaction. Consequently, the neutron distribution, and also the neutron shell closure is also reflected in the electric charge radii.

II. Traditional magic neutron numbers

By the early seventies, optical isotope shift (OIS) measurements were performed on several isotopic series. The *relative* accuracy of this method is very high. Using these early data (294), it has been demonstrated [1] that the mass number dependence of *rms* charge radii does not follow a smooth power function e.g. $A^{1/3}$, but it has a characteristic fine structure: a decrease before magic neutron numbers and a strong increase after it.

Now, several decades later, having much more (909) data [2] – most of them off the valley of stability -, it is worth while investigating the problem again by plotting the radii of elements in the function of the neutron number. In order to stress the fine structure, experimental radii R_{exp} were normalized by a smooth power function of the mass number *A*; i.e. the normalizing function

$$R_{norm}(N) = R_0\left(\frac{A}{A_0}\right)^k, \qquad N = N_0 + \Delta N, \qquad A = A_0 + \Delta N \tag{1}$$

was applied, where R_0 is the *rms* radius of the reference isotope with neutron number N_0 and mass number A_0, respectively. As to the value of the exponent, $k = 1/6$ was chosen as a result of an over-all statistical fit for a wide mass number interval, see eq. (9), fig. 2 and tab. 3 in [3]. The results R_{exp}/R_{norm} are shown on figures 1 through 3. Owing to the high relative accuracy of the OIS method, in most cases the error bars would be less then the data symbols.

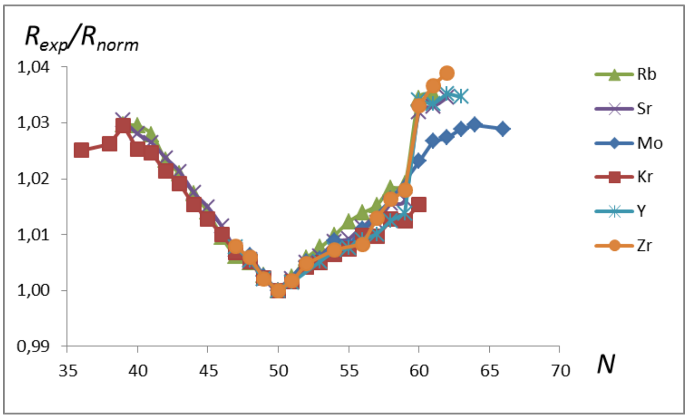

Figure 1. Normalized charge radii of Kr, Rb, Sr, Y, Zr and Mo isotopes. The effect of $1g_{9/2}$ neutron shell closure at $N = 50$ is clearly seen.

Figure 1 shows the normalized radii R_{exp}/R_{norm} for six isotopic chains that contain the neutron number N = 50. As can be seen, all series have almost the same neutron number dependence: a minimum at the magic neutron number N = 50 ($1g_{9/2}$) in the case of all elements, i.e. *independently of the number of protons!* The neutron-proton interaction is so strong that it forces the neutron shell structure on the distribution of protons. In some elements, at N = 60 a sudden increase can also be observed. This is caused by the onset of stable deformation; it can be interpreted by the non-spherical isoscalar *n-p* interaction between valence neutrons and protons, see e.g. [4] and references therein. Similar figures can be obtained for the other traditional magic neutron numbers

N = 28, 82 and 126, corresponding to the closure of neutron shells $1f_{7/2}$, $2d_{3/2}$ and $3p_{1/2}$, respectively.

III. Non-traditional magic neutron numbers

For light nuclei the picture is more complicated. An earlier statistical study [4] of deviations of rms charge radii from the droplet model values has shown that 6 ($1p_{3/2}$) and 14 ($1d_{5/2}$) should also be taken into account as new *non-traditional* magic numbers. On figure 2 the normalized radii of a few light elements are plotted in the function of the neutron number *N*.

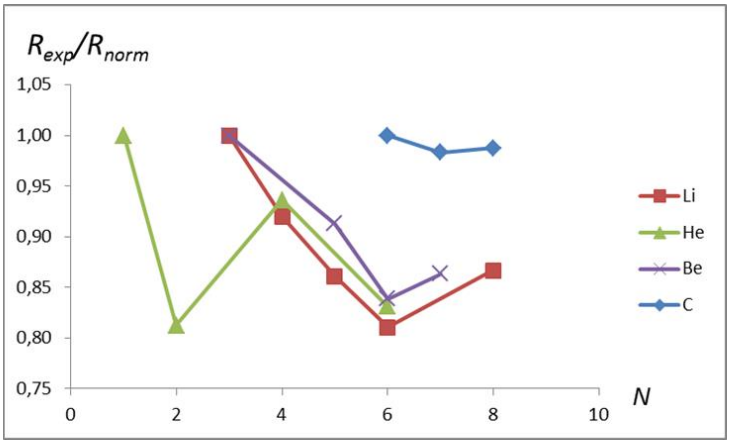

Figure 2. Normalized charge radii of He, Li, Be and C isotopes. The effect of the non-traditional magic neutron number N = 6 can be observed.

In the case of helium the effect of the traditional N = 2 ($1s_{1/2}$) magic number is clearly seen, and a decrease towards N = 6. For lithium a remarkable minimum is at N = 6, followed by an increase to N = 8 ($1p_{1/2}$), i.e. for A = 11. This isotope ^{11}Li is a *halo nucleus*: the last neutron pair behaves like a neutron cloud far from the high-density core of the nucleus. Actually, this is the first halo nucleus discovered and treated theoretically [5, 6]. The attraction of these distant neutrons forces the core protons to higher radii. The series for Be behaves similarly. On the other hand, carbon isotopes do not show this tendency, may be because they are closer to the valley of stability, where the effect of traditional magic numbers, e.g. N = 8, prevail.

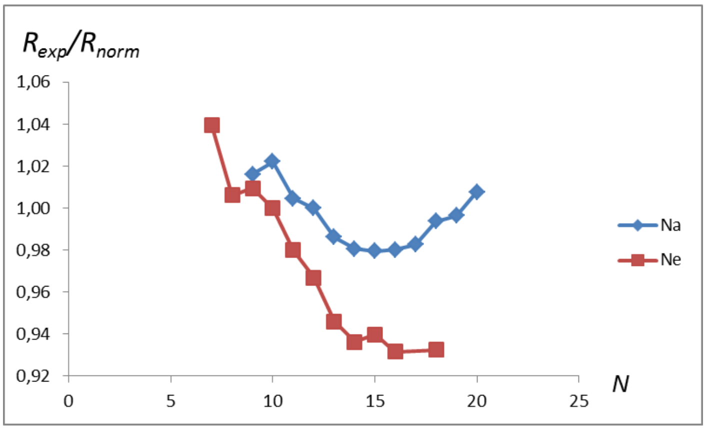

Figure 3. Normalized charge radii of Ne and Na isotopes. The wide minimum around N = 14 – 16 suggests a „mixed" closure of $1d_{5/2}$ and $2s_{1/2}$ neutron shells.

On figure 3 the normalized radii of neon and sodium isotopes are plotted. The series for Na shows a broad minimum between N = 14 and 16, which can be interpreted as the manifestation of a „mixed" closure of $1d_{5/2}$ and $2s_{1/2}$ neutron shells. The series for Ne – although not long enough - confirms this inference with a slightly stronger stress on N = 16.

IV. Isotonic series: magic proton numbers

Due to the particularities of the different measuring methods, isotonic series are not independent of each other. Therefore, only one series is plotted for a given atomic number range. Here, the exponent $k = 1/2$ was used in Eq. (1), see fig. 2 and tab. 3 in [3]. The traditional magic proton numbers Z = 28, 50 and 82 can easily be observed. As an example, the isotonic series for N = 70 is shown in Figure 4, where the minimum at Z = 50 corresponds to the closure of the $1g_{9/2}$ proton shell.

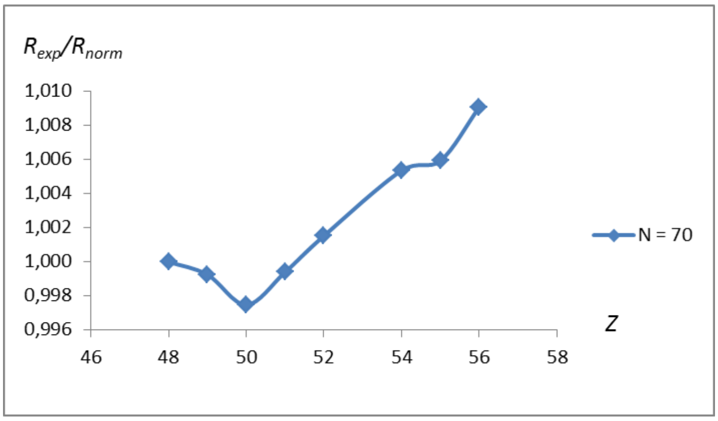

Figure 4. Normalized charge radii of isotones with N = 70. The minimum at Z = 50 belongs to the closure of the $1g_{9/2}$ proton shell.

In the region of light nuclei there are only few and short isotonic series. Figure 5 shows the series for N = 8. This plot does not show a minimum at the traditional Z = 8 but follows a decreasing tendency towards Z = 6; this confirms the earlier observations based on a statistical treatment [4].

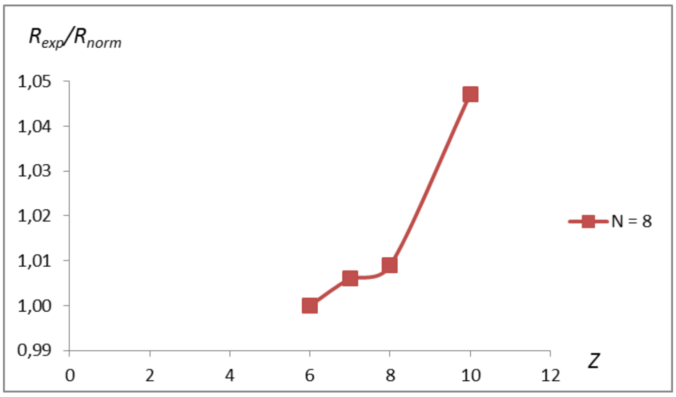

Figure 5. Normalized radii of isotones with N = 8. The decreasing tendency towards Z = 6 - instead of Z = 8 - confirms earlier observations [4].

References

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