Clusters in the Dynamic Lattice Model of the Atomic Nucleus

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The Dynamic Lattice Model proposed here is based on the generally unknown fact that the magic numbers are a symmetry feature of the face centered cubic (fcc) lattice, and not primarily a feature of nuclear physics, the field in which the magic numbers have been discovered. The author does not believe that the same magic numbers occur accidentally in both areas; he claims that the agreement exists because nuclei are structured as an fcc lattice themselves. This far-reaching claim could not be made until recently, when in addition to the series of lower magic numbers 2, 8, 20, and 40 a new series of higher-leading magic numbers 14, 28, 50, 82, and 126 was found by the author also to be a feature of the fcc lattice. This information is presented here for the first time.

Since doubly magic self-conjugate nuclides are known to be spherical, one has to search for the highest 3-dimensional symmetry, because it is automatically spherical.

We require the shapes to be similar and obtain the following series which starts with a tetrahedron followed by truncated tetrahedra (Fig. 1).

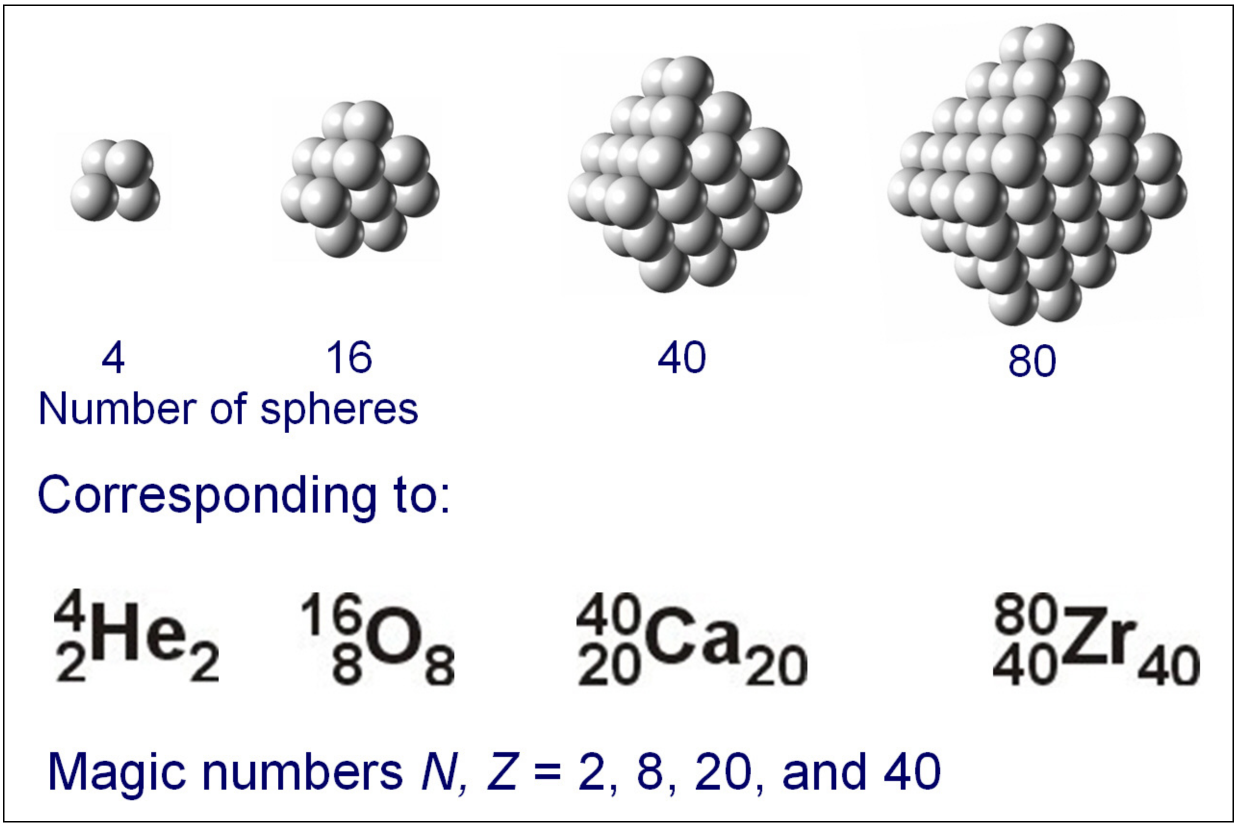

Fig. 1. Series of tetrahedra

The new series containing the higher magic numbers has indentations of 0, 3, 7, 12, and 18 lattice positions on each of the four pair-wise opposing planes. The ridges thus created lead to a reduced Coulomb repulsion and therefore to a larger binding energy. This favours the transition to the second series of magic numbers shown in Fig. 2.

The symmetry is the highest possible. There are 3 orthogonal pairs of symmetry planes. Every plane has an angle of 90° with one other plane and 60° with the other 4 planes.

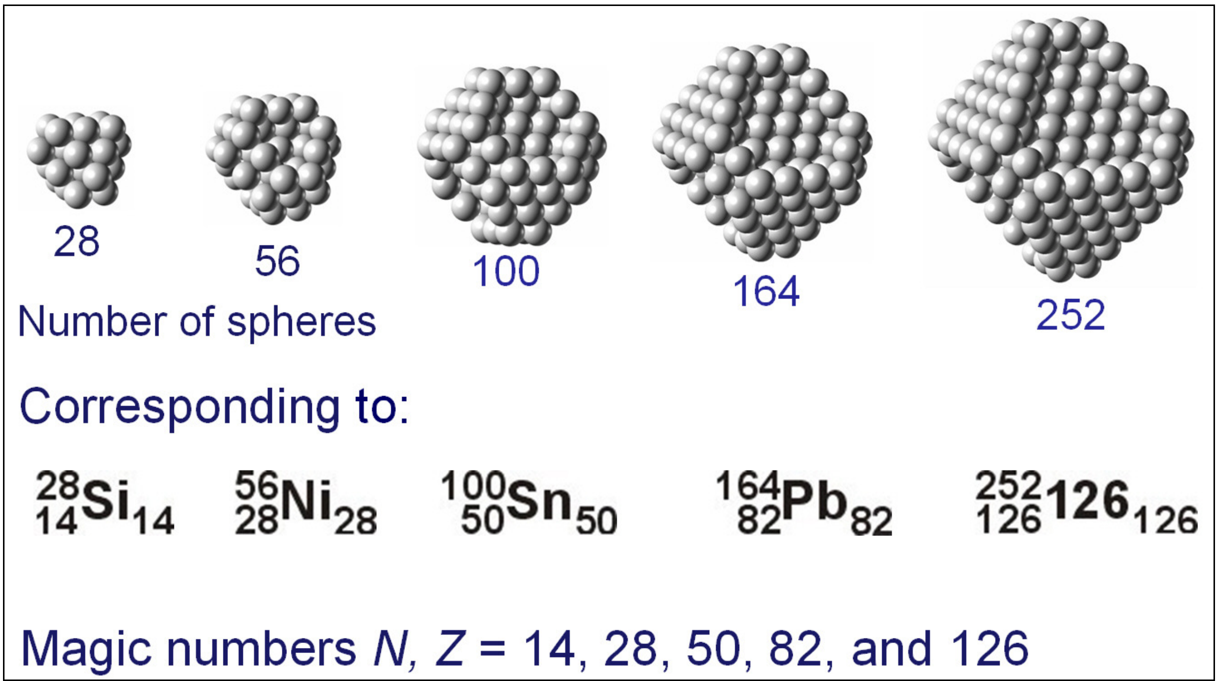

Fig. 2. Second Series of truncated tetrahedra with indented surfaces from 56 on

All this suggests that nucleons are arranged in a lattice as maxima of standing nucleon waves moving on rectangular paths. In the absence of an attracting center as in the atom, the path inside the nucleus should be straight. At the border, the nucleon is reflected by 90 (or 180) degrees and the path leads back into itself.

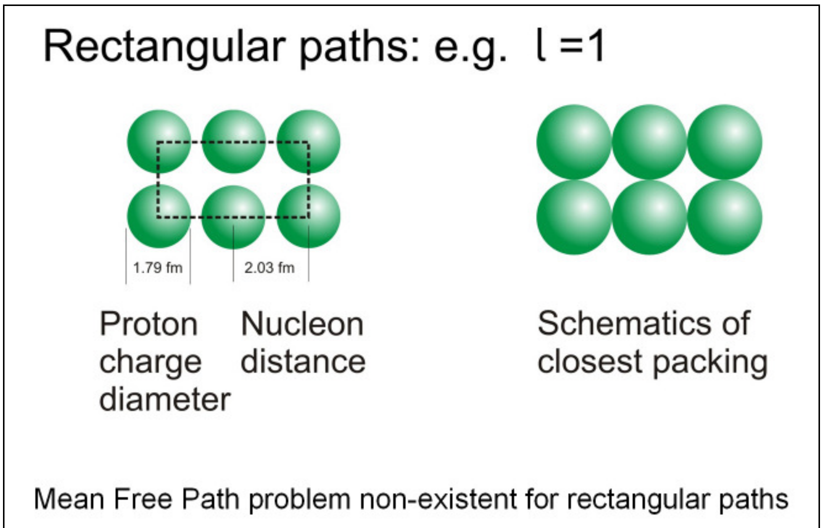

Fig. 3. Example of a rectangular orbit with l=1

This concept eliminates the long-standing problem that the other nucleons are conceived to obstruct the orbiting, since half the nucleus is occupied with nuclear matter and the mean-free-path is only 3 to 5 fm.

Amazingly, the orbital angular momenta with their occupation numbers fit this system perfectly. This is shown in Fig. 4 for different l-values, in Fig. 5 for ^{4}He and ^{16}O, and in Fig. 6 for ^{40}Ca.

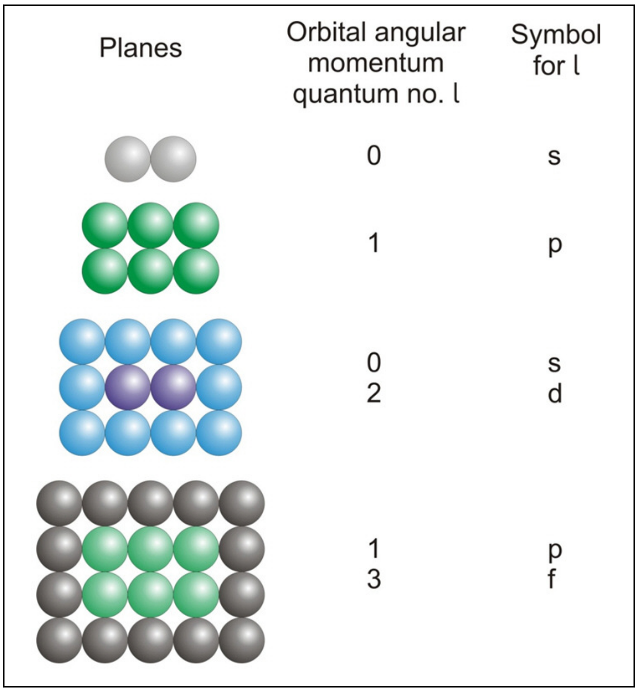

Fig. 4. Planes for different l-values

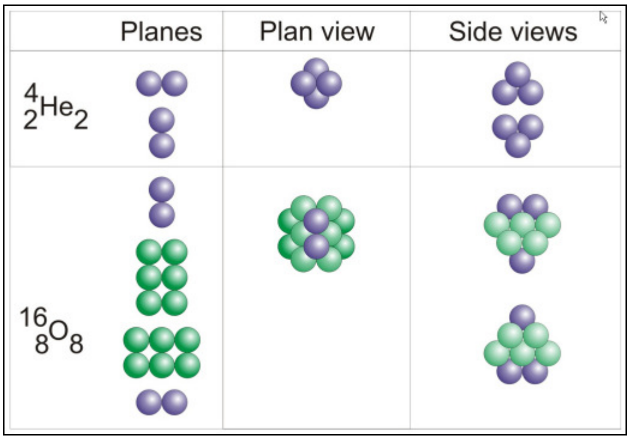

Fig. 5. Structure of ^{4}He and ^{16}O

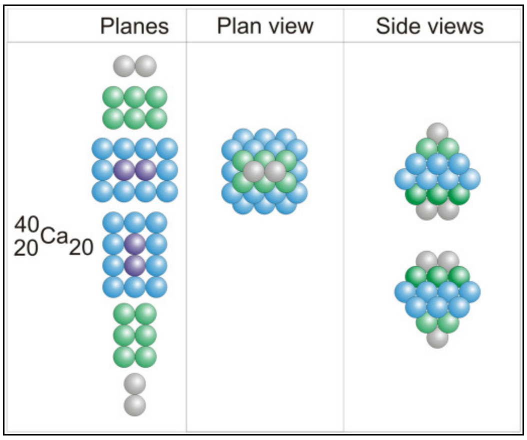

Fig. 6. Structure of ^{40}Ca

It is assumed that the nucleons of a given sub-shell are evenly distributed on the rectangular path also in the case of partial occupation. As a consequence, the binding energies show linear trends within the sub-shells if the first 0^+ levels are used at the harmonic oscillator shell closures A=16 and 40 [1]. At ^{4}He, a reference point at 7.46 MeV is used because a level is not possible there. In this diagram, the steep decrease of the negative binding energy is compensated by a term linear in A.

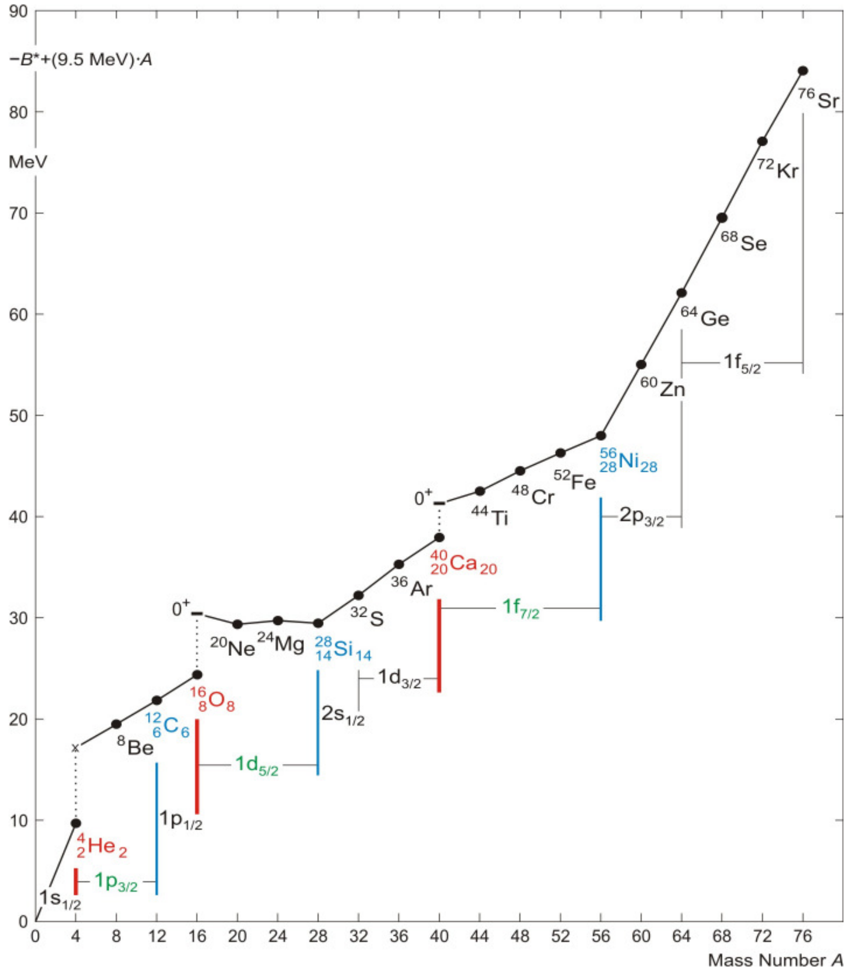

Fig. 7. Step phenomenon in the binding energies of self-conjugate even-even nuclides

The steps are interpreted as rearrangement of the nucleons before the subshell is filled successively [1]. At ^{28}Si and ^{56}Ni, the break is characteristic for these doubly magic nuclides.

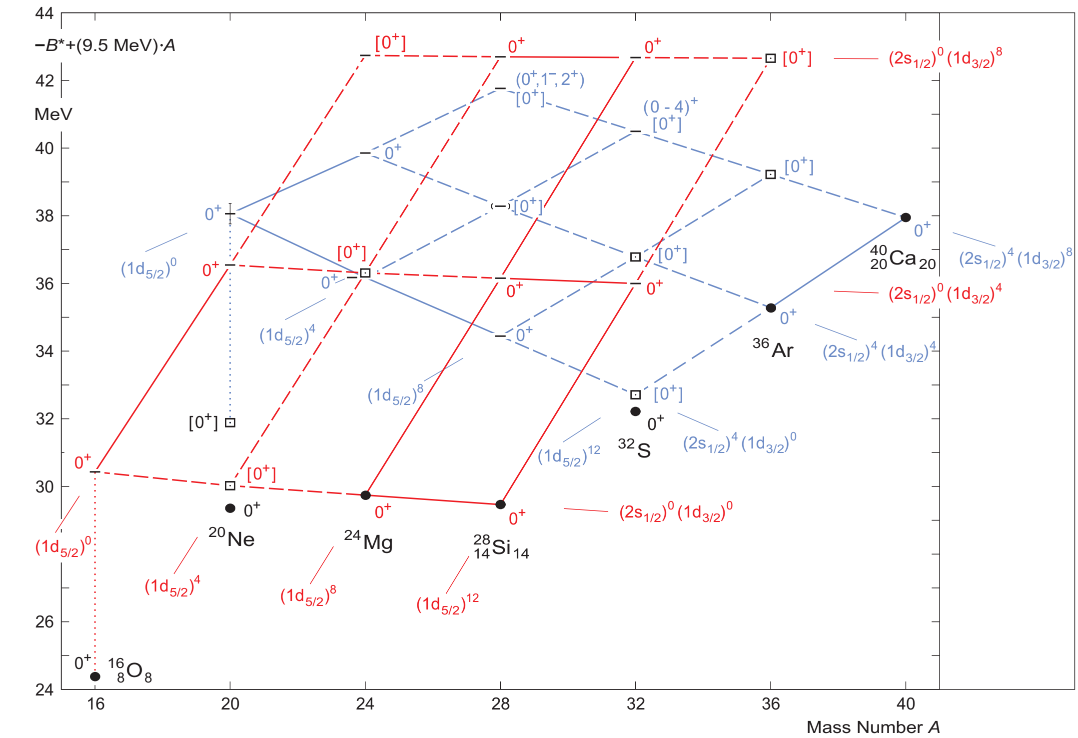

Fig. 8. Two approximate parallelograms connecting empty and filled $2s_{1/2}$ sub-shell states respectively

This diagram [1] shows that the build-up of the nuclides can be achieved in any sub-shell order. The larger parallelogram contains states in which the $2s_{1/2}$ sub-shell is empty, while it is fully occupied in the smaller parallelogram.

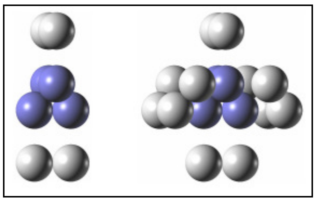

Fig. 9. The probability distribution of $2s_{1/2}$ states in ^{40}Ca

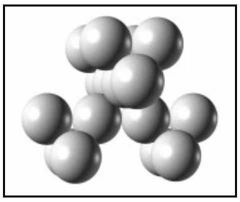

Fig. 10. Alpha-cluster state of ^{16}O

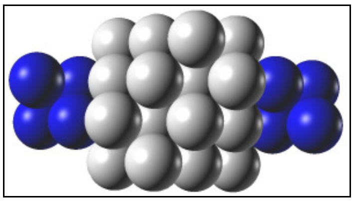

Fig. 11. Super-deformed ^{36}Ar

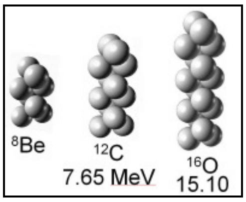

Fig. 12. Tentative chain states

The magic nuclei can be considered to have alternating proton and neutron planes, but their orientation should not be fixed. This is shown (Fig. 9) for the two $2s_{1/2}$ pairs of ^{40}Ca. Their probability is distributed spatially symmetric over the positions shown. For clarity, the p- and d-orbits are omitted. They are correspondingly distributed and therefore mixed with each other and the s- states.

Cluster states are sections of this lattice. As an example, ^{16}O is shown (Fig. 10) as composed of 4 alpha particles.

In addition, the super-deformed ^{36}Ar state (Fig. 11) with an axis ratio of 1:2 is shown.

Tentative chain states for the excitations given (in MeV) would look as shown in Fig. 12.

In the case of self-conjugate nuclides the equal number of protons and neutrons cannot be localized, e. g. in alternating planes, because their orientation is not defined. Therefore we must assume at every lattice position a 50% occupancy of protons and neutrons.

In the last figure, we see doubly magic nuclides which are – as they have been shown to be – approximately spherical. The red spheres show proton positions of 50% occupancy and the blue ones a skin of 50% neutron occupancy.

In the simplest case, ^{42}Si, the skin comprises 40 lattice positions half-occupied by neutrons and 12 lattice positions half-occupied by protons. Under this skin the fully-occupied lattice positions comprise the second configuration given in Fig. 1 corresponding to ^{16}O.

Under each of the 4 blue faces of the larger doubly magic nuclides in Fig. 13, there is an additional layer of 50% occupied neutron positions, comprising 3 in ^{78}Ni, 7 in ^{132}Sn and 12 in ^{208}Pb.

It is interesting that, with respect to the configurations of the second series (Fig. 2), each protruding facet of a configuration fits exactly into the corresponding indentation of the next larger configuration; therefore the formation of doubly magic nuclides with neutron excess is considerably simplified.

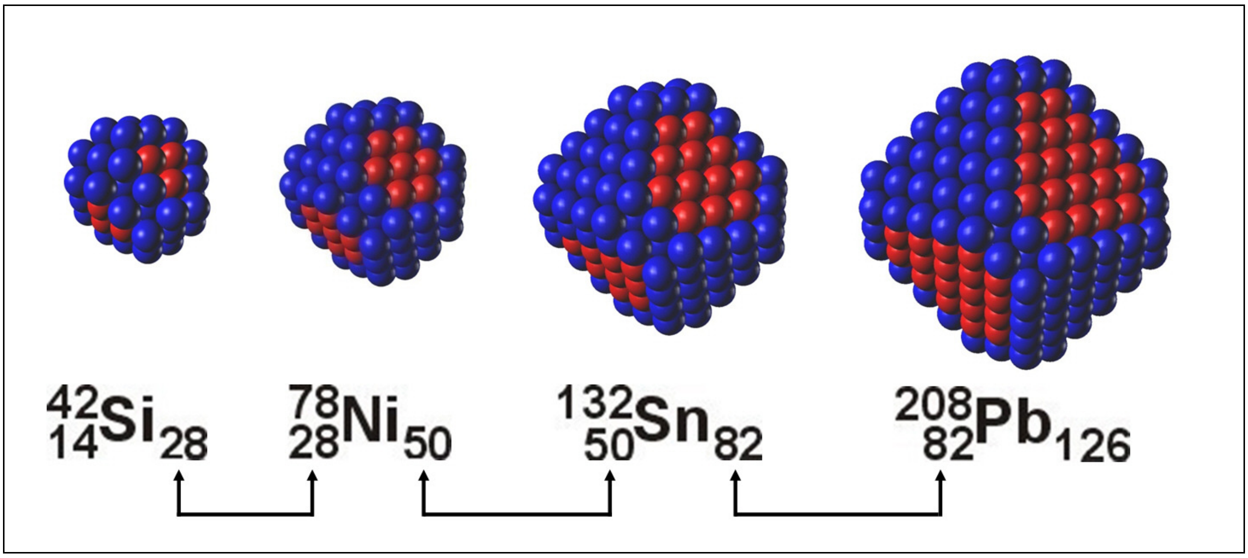

Fig. 13. Doubly magic nuclides with neutron excess

In conclusion, atomic nuclei are considered to have a face centered cubic lattice structure because the magic numbers, originally discovered in nuclear physics, are primarily a symmetry feature of that lattice. Cluster states are shown as sections of the lattice.

References

[1] F. Everling, J. Phys. Soc. Jpn. **75** (2006) 124201-1 - 124201-13