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Letter to the Editor

New Magic Numbers and Their Significance

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Nuclear engineers are well aware of the importance of the closed nuclear shell "magic numbers" to nuclear engineering.[1] From Wikipedia, "In nuclear physics, a magic number is a number of nucleons (either protons or neutrons) such that they are arranged into complete shells within the atomic nucleus. The seven most widely recognized magic numbers as of 2007 are 2, 8, 20, 28, 50, 82, and 126 [for neutrons]."[2] Magic numbers are responsible for double-hump fission curves, the existence of delayed neutrons, and xenon poisoning and xenon-induced power oscillations in reactors.

In a previous Letter to the Editor,[3] we have explained the origin of the magic numbers as a combination of six shell fillings, following the pattern, from out to in, of 50, 32, 18, 18, 8, and 2. Using this distribution, we developed a new semi-empirical binding energy formula that fits 3000+ isotopes, reproduces the low-A peaks, and gets all the spins right.[4] We have been able to verify the spatial locations of the nucleons for several isotopes by a numerical iteration that minimizes the binding energy of the nucleus. The difference between before and after states for several reactions quantitatively agrees with experimental decay data.[5] This model has now been extended[6,7] to predict 12 new magic numbers that explain several old and new phenomena such as the extent of the superheavy isotope distribution and the fission product distributions.

A basic premise of the model is that it is impossible for stable shells to exist in a packed nucleus if the nucleons are in motion. Instead, they assume static positions in a situation of force balance and at most vibrate around these positions. Vibration of large groups of nucleons is the accepted model for liquid drop fission. Vibration of a group of nearby nucleons is responsible for alpha decay, and we contend that internal vibration of a neutron or a proton is responsible for beta decay and positron decay, respectively.

Note that there are actually two shells of 18 protons and neutrons available and that an 18-neutron shell can refill to 32 and a 32-neutron shell can refill to 50. This is analogous to inner electron shells refilling to a larger number for the rare earths and the actinides. Hence, new magic numbers such as 58, 68, and 76, first suggested by Pauling,[8] plus 90, 100, 108, and 118, and new magic neutron numbers such as 140, 158, 164, 172, and 182 can be formed for the continent containing the stable isotopes, the peninsula containing the actinides, and the shoal and island of superheavy isotopes. These new numbers have been verified against data in the "Table of Isotopes."[9] It has subsequently been shown that using the new magic number 58, the new light fission product pair (28, 58) in conjunction with the heavy pair (50, 82) gives excellent agreement with the ^{235}U fission product distribution[7] and shows consistency for different fissionable isotopes[10] (see Fig. 1).

There are other proofs of the new magic numbers. For example, the doubly magic isotope ^{140}Ce has 58 protons and 82 neutrons and comprises 90% of stable cerium. A group at Dubna[11] has an analysis method that verifies 58 as well as 50 and 82. The next heaviest doubly magic nucleus beyond ^{208}Pb is long-lived ^{230}Th at 90 protons and 140 neutrons. The longest-life isotope of fermium at $Z = 100$, which has 19 known isotopes, is ^{257}Fm, with a half-life of 100 days. Doubly magic ^{258}Fm is unstable to spontaneous fission, but the slight asymmetry of the odd nucleus one short of double magic at $N = 158$ satisfies the Seaborg criterion and produces this long half-life. Heavier isotopes are not expected to be long-lived.

An examination of the experimentally measured nuclear density shapes gives an important clue as to what is happening. The density of nucleons at their nuclear centers decreases somewhat with increasing size or mass of the nucleus. On the other hand, the nuclear density data seem to indicate that the proton and neutron shells do not remain in a stable configuration once they are filled and additional nucleons are added to make heavier nuclides. Rather, at some point, the balance of electric and magnetic forces in the nucleus is such that the smaller interior shells rearrange into larger shells that are more strongly bound. Thus, the average nuclear density near the center of the nucleus drops because the small innermost shells are empty or partially empty.

It should also be remarked that the shells have no fixed radial boundaries, so that the proton and neutron shells at the

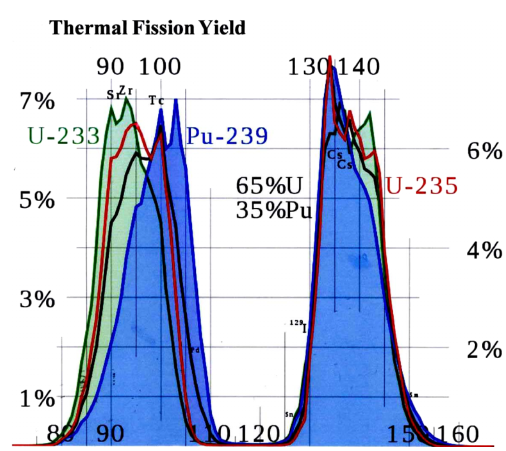

Fig. 1. Fission product distributions versus mass number A (attribution: JWB at en.wikipedia[10]).

same level can spatially overlap and expand to fill space, and empty inner shells can squeeze down to allow nucleons to reside where they have minimum energy. Hence, the nuclear density experiments are consistent with relatively constant volumetric filling.

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