

Evolution of the $N = 50$ gap from $Z = 30$ to $Z = 38$ and extrapolation toward ^{78}Ni

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The evolution of the $N = 50$ gap is analyzed as a function of the occupation of the proton $\pi f_{5/2}$ and $\pi p_{3/2}$ orbits. It is based on experimental atomic masses, using three different methods of one- or two-neutron separation energies of ground or isomeric states. We show that the effect of correlations, which is maximized at $Z = 32$ could be misleading with respect to the determination of the size of the shell gap, especially when using the method with two-neutron separation energies. From the methods that are the least perturbed by correlations, we estimate the $N = 50$ spherical shell gap in $^{78}\text{Ni}_{50}$. Whether ^{78}Ni would be a rigid spherical or deformed nucleus is discussed in comparison with other nuclei in which similar nucleon-nucleon forces are at play.

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I. INTRODUCTION

The persistence of the magic numbers remained a dogma for several decades until the growing possibilities of exploring nuclei far from stability have revealed that several magic shell gaps were fragile. In particular, the neutron-rich nuclei $^{12}\text{Be}_8$, $^{32}\text{Mg}_{20}$, and $^{42}\text{Si}_{28}$ were found to exhibit large collectivity in spite of their “magic” neutron numbers $N = 8, 20$, and 28 (see for instance [1–3]). This disappearance of traditional magic numbers was ascribed to so far unexplored nuclear forces which act to reduce the size of the spherical shell gaps [4]. Consequently nucleon excitations across these reduced gaps become easier, increasing the amount of multiparticle multi-hole configurations. Nuclei exhibiting these large correlations are usually deformed.

We have recently reviewed the major structural features along the isotonic and isotopic chains around the spherical magic numbers [5]. By the way we have pointed out the role of spin-flip interactions between protons and neutrons to modify the harmonic oscillator or spin-orbit magic shells in a consistent manner (see the various examples displayed in Figs. 45 and 46 of Ref. [5]). We surmised in particular that nuclear forces were acting to reduce the $N = 50$ gap when Z decreases toward $Z = 28$. If true this would jeopardize the magicity of $^{78}\text{Ni}_{50}$. On the other hand, recent values of atomic masses measured with high precision using Penning trap mass spectrometers [6,7] were interpreted in favor of a reinforced rigidity of the $N = 50$ gap toward ^{78}Ni .

The aim of the present work is to present a detailed discussion on the evolution of the $N = 50$ gap from $Z = 28$ to $Z = 38$, which includes the new high-precision mass measurements. We show in particular the sensitivity of the obtained conclusions with the methods used to derive the shell gap, taking the one or two neutron separation energies from ground or isomeric states. We propose an interpretation of these discrepancies, and extrapolate the size of the $N = 50$ gap to ^{78}Ni using what we consider to be the least biased method.

II. THE $N = 50$ GAP EXTRACTED FROM THE PROPERTIES OF THE $N = 51 - 50 - 49$ ISOTONES

Following Ref. [5], we use the binding energy of the last nucleon as a single-particle energy¹ to study the evolution of the two orbits $g_{9/2}$ and $d_{5/2}$ between which the $N = 50$ spherical gap is formed. The Appendix of Ref. [5] has warned the reader about the limitations of such a method, as for isotopes and isotones having a doubly magic $N = Z$ core or for nonrigid nuclei. In the latter case, the total binding energies of the ground states do contain some correlation energies (from vibrational motion, for instance) which shift the value of the binding energy of the last nucleon.

Between $Z = 28$ and $Z = 38$, protons occupy the $\pi f_{5/2}$ and $\pi p_{3/2}$ orbits. Therefore the evolution of the size of the $N = 50$ shell gap depends on proton-neutron interactions between the protons in the $\pi f_{5/2}$ and $\pi p_{3/2}$ orbits and the neutrons in the $\nu g_{9/2}$ and $\nu d_{5/2}$ orbits. The low-energy structure of the $N = 50$ isotones having odd- Z values indicates that the $\pi f_{5/2}$ and $\pi p_{3/2}$ orbits are very close to each others as the $3/2_1^-$ and $5/2_1^-$ states lie close in energy (see Fig. 1). Therefore it is reasonable to assume that the two proton orbits are filled simultaneously within the $Z = 28-38$ range and that the proton-neutron monopole interactions at work are averaged values between V_{f5-g9}^{pn} and V_{p3-g9}^{pn} below $N = 50$ (denoted as $\bar{V}_{f5/p3-g9}^{pn}$), and between V_{f5-d5}^{pn} and V_{p3-d5}^{pn} above $N = 50$ ($\bar{V}_{f5/p3-d5}^{pn}$).

The new high-precision atomic masses of $^{83,82,81}_{32}\text{Ge}$ [6] and $^{81,80,79}_{30}\text{Zn}$ [7] allow to display the binding energies of the last neutron in the $N = 51$ and 50 isotones in Fig. 2(a). This figure improves and enlarges Fig. 28 of Ref. [5]. We observe a quasilinear evolution of the BE_{1n} values, with the exception of the $BE_{1n}(50)$ value at $Z = 32$. We discuss below the origin of this large singularity at $Z = 32$.

The binding energy of the last neutron in $^{82}_{32}\text{Ge}_{50}$ lies about 300 keV above the linear fit [see the red triangles and the

¹Such a relation means that the binding energy of the last nucleon, noted $BE_{1n}(N)$ for the neutron, is a negative quantity, i.e., the inverse of the separation energy, noted $S_{1n}(N)$.

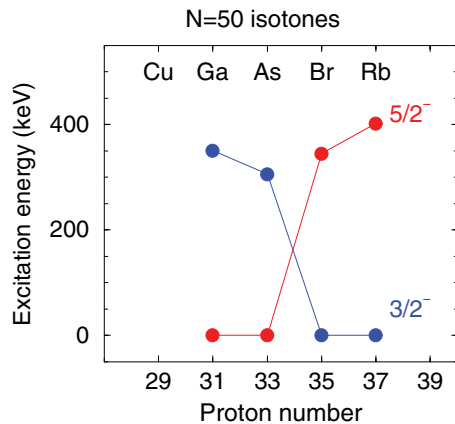


FIG. 1. (Color online) Energy of the two first states of the $N = 50$ isotones having an odd- Z value [8].

red dashed line in Fig. 2(a)]. This leads to a singularity at $Z = 32$ which might be viewed as arising from the presence of a subshell closure. Under this assumption two slopes in the binding energies would be observed, one corresponding to the filling of the $\pi p_{3/2}$ orbit until $Z = 32$ and the other to the filling of the $\pi f_{5/2}$ orbit afterwards. However, both the observed ordering of the two orbits for $Z \leq 33$ and their near degeneracy (see Fig. 1) are strong arguments against the presence of such a subshell closure. Therefore it is reasonable to think that this singularity at $Z = 32$ originates from the presence of deformation. The $BE_{1n}(50)$ value for ^{82}Ge involves the binding energies of the $^{81,82}\text{Ge}_{49,50}$ nuclei. In order to determine whether $BE_{1n}(50)$ contains some amount of correlation energy, the structure of $^{81}\text{Ge}_{49}$ has to be examined. The ground states of the $N = 49$ isotones are $9/2^+$, likely originating from a $(\nu g_{9/2})^{-1}$ spherical configuration. The first excited states of the $N = 49$ isotones with $Z \geq 34$ has $I^\pi = 1/2^-$, it is likely to be of $(\nu p_{1/2})^{-1}$ origin. The excitation energies of the $1/2^-$ states are slightly reduced with decreasing Z , i.e., 389 keV in ^{87}Sr , 305 keV in ^{85}Kr , and 228 keV in ^{83}Se . When extrapolated to ^{81}Ge , the excited $1/2^-$ state would be expected close to the $9/2^+$ ground state. Surprisingly its energy is as large as 895 keV [10]. This suggests that the $9/2^+$ ground state contains some additional correlation energy which decreases the atomic mass of ^{81}Ge , shifting in turn the binding energy of the last neutron in ^{82}Ge . Discoveries of the excited states built on the ‘collective’ $9/2^+$ ground state and/or measurements of the $E2$ transition probabilities would ascertain the shape change of ^{81}Ge as compared to the heavier isotones. Unfortunately no excited state with $I^\pi > 9/2^+$ is known at the present time [8].

To perform the two linear fits drawn in Fig. 2(a), we have chosen to eliminate the data at $Z = 32$ and $Z = 38$ as well, since ^{88}Sr has the main properties of a doubly magic nucleus (it is used as an inert core in many shell model calculations of nuclei with $Z, N \leq 50$). Indeed when a closed shell is reached, a sudden reduction of correlation energies in principle occurs, leading to a variation of the experimental binding energy of the last neutron as mentioned in the Appendix of Ref. [5]. Thus taking into account the data at $Z = 30, 34,$ and 36 , linear fits with slopes of $|\bar{V}_{f5/p3-g9}^{pn}| = 0.60$ MeV and $|\bar{V}_{f5/p3-d5}^{pn}| = 0.48$ MeV are obtained for $BE_{1n}(50)$ and $BE_{1n}(51)$, respectively.

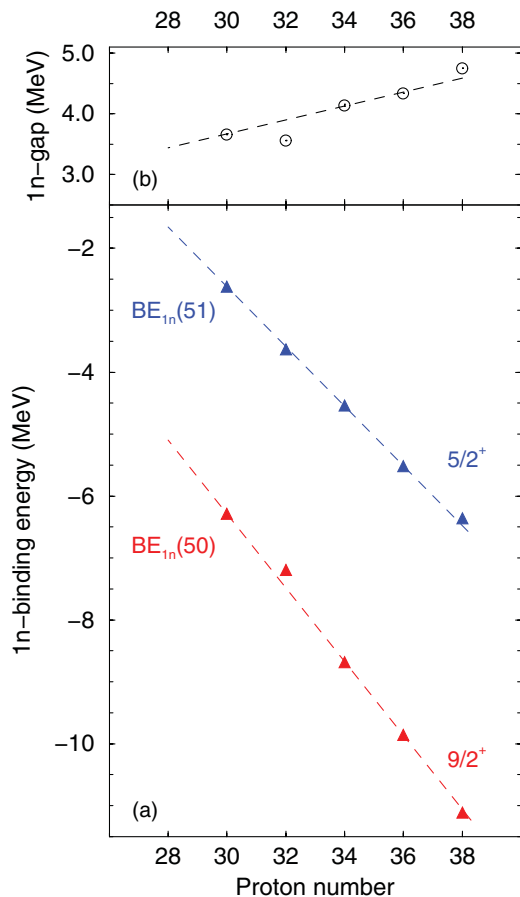


FIG. 2. (Color online) (a) Experimental binding energies of the states $9/2^+$ ($5/2^+$) located below (above) the $N = 50$ magic number. The experimental values of the atomic masses are from Refs. [6,7,9]. The uncertainties are smaller than the symbols. (b) Difference in binding energies of these two states surrounding the gap at $N = 50$. The dashed lines are the linear fits using the data at $Z = 30, 34, 36$ (see text).

The difference of the two binding energies, $BE_{1n}(51) - BE_{1n}(50)$, gives the size of the correlated gap, which is drawn in Fig. 2(b). The linear fit gives an extrapolated value at $Z = 28$ of 3.44 MeV. However this extrapolated value will be enhanced if a reduction of correlation occurs at $Z = 28$ as it does at the $Z = 38$ shell closure (the increase of the gap is 0.17 MeV here). We shall come back to this point in Sec. V. Before this, we compare the present conclusions obtained with one-neutron binding energies to those derived when using two-neutron binding energies, a method which is more extensively used in the literature.

III. EVOLUTION OF THE $N = 50$ GAP FROM THE PROPERTIES OF THE $N = 52 - 50 - 48$ ISOTONES

The behavior of the two-nucleon separation energies is a widely used indicator of structural evolution as for the emergence of magic numbers. For instance, the two-neutron separation energies of each isotopic chain display a sudden drop after the magic number when plotted as a function of the neutron number, as for instance shown in Fig. 2 of

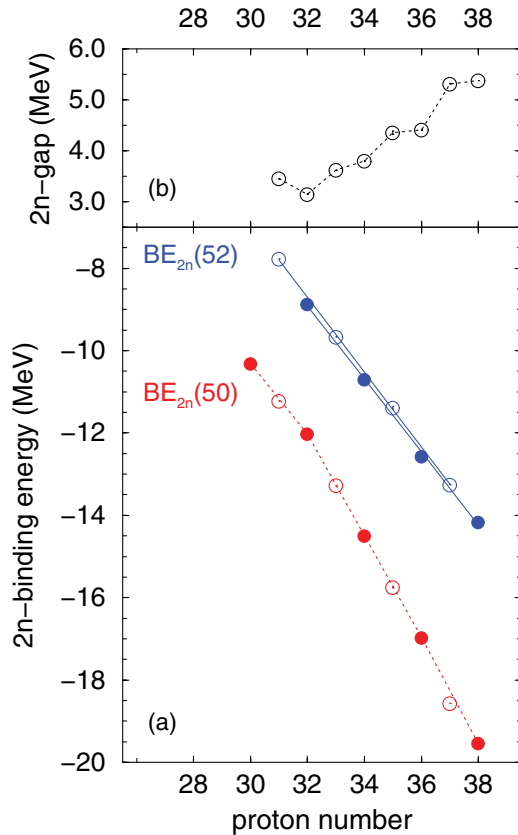


FIG. 3. (Color online) (a) Experimental binding energies of the two last neutrons in the $N = 52$ isotones and the $N = 50$ isotones. Experimental atomic masses are taken from Refs. [6,7,9]. The uncertainties are smaller than the symbols. (b) Difference of the two-neutron binding energies between the $N = 52$ and $N = 50$ isotones.

Ref. [6]. Similarly, when plotted as a function of the proton number, two neutron separation energies corresponding to each isotonic series form almost parallel and equidistant sequences, displaying a sudden gap at the magic number. Such a plot is drawn in Fig. 3 of Ref. [6] where the evolution of the $N = 50$ shell gap energy toward ^{78}Ni is discussed.

We show in Fig. 3(a) the two-neutron binding energies using the same conventions as those of Fig. 2 for the purpose of comparison. When determining the evolution of shell gaps using two neutron binding energies at $N = 50$, the masses of three isotopes, $N = 48, 50, 52$, are involved. Assuming that there is no rearrangement or collective excitation when adding or removing two neutrons from the semimagic ($N = 50$) cores, i.e., the $N = 52$ and $N = 48$ isotones are rigid spherical,² the $BE_{2n}(52)$ and $BE_{2n}(50)$ values are directly related to the binding energies of the $\nu d_{5/2}$ and $\nu g_{9/2}$ orbits, respectively. Thus their variations are expected to be quasilinear, the slope being obtained from the average monopole proton-neutron interaction involved, as discussed in Sec. II. Moreover the BE_{2n} values should only depend on the occupation rate of

²Then their spectra would only display the states from the j_n^2 configuration, their spacings in energy being due to the two-body residual interactions.

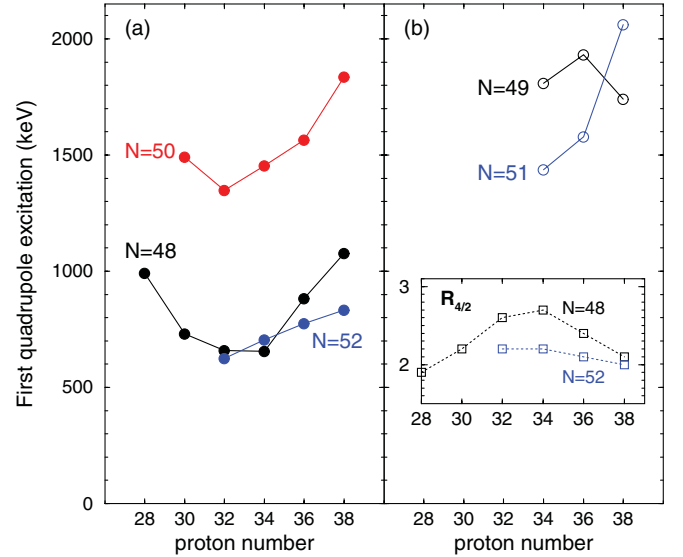


FIG. 4. (Color online) Energy of the first quadrupole excitation built on the ground state of the nuclei of interest: (a) The $2_1^+ \rightarrow 0_{g.s.}^+$ transitions of the even-even nuclei. (b) The $13/2_1^+ \rightarrow 9/2_{g.s.}^+$ transitions of the $N = 49$ isotones and the $9/2_1^+ \rightarrow 5/2_{g.s.}^+$ transitions of the $N = 51$ isotones. The $E(4_1^+)/E(2_1^+)$ ratios, $R_{4/2}$, for the $N = 52$ and $N = 48$ isotones are shown in the inset. The experimental information is from Refs. [8,11–14].

the $\pi f_{5/2}$ and $\pi p_{3/2}$ orbits, whatever the parity of Z (even or odd). Figure 3(a) shows that the $BE_{2n}(50)$ trend exhibits a kink at $Z = 32$ and that the $BE_{2n}(52)$ values obtained for odd- Z and even- Z nuclei do not belong to the same straight line, meaning that the criterion of rigid spherical shapes is not met. As a result, the gap derived from the difference of two-neutron binding energies, $BE_{2n}(52) - BE_{2n}(50)$, shown in Fig. 3(b) displays a complex behavior with (i) a staggering as a function of the parity of Z and (ii) a change of slope at $Z = 32$. By pursuing $BE_{2n}(50)$ trend from $Z = 32$ to $Z = 28$ one would find an increase of the $N = 50$ gap when reaching ^{78}Ni [6], contrary to what was derived in Sec. II.

We suspect that extra nuclear correlations, which would be maximized at $Z = 32$, are responsible for this apparent change of slope at $Z = 32$. A good indicator of extra correlations can be revealed by the changes in the energy of first quadrupole excitation built on the ground states. The experimental results measured in the five isotonic chains ($N = 48$ – 52) are used for that purpose, namely (i) the energies of the $2_1^+ \rightarrow 0_{g.s.}^+$ transitions of the $N = 48, 50, 52$ nuclei, (ii) the energies of the $13/2_1^+ \rightarrow 9/2_{g.s.}^+$ transitions of the $N = 49$ isotones, and (iii) the energies of the $9/2_1^+ \rightarrow 5/2_{g.s.}^+$ transitions of the $N = 51$ isotones (see Fig. 4).

The 2_1^+ excitation of the semimagic $N = 50$ nuclei, which is due to their proton configuration, lies between 1.35 MeV and 1.84 MeV [Fig. 4(a)]. The $N = 51(49)$ isotones [Fig. 4(b)] display similar values to those of their $N = 50$ cores, that is expected if the neutron particle (hole) is weakly coupled to the proton excitation of the core.³

³Within the weak-coupling scheme, the odd- N nucleus exhibits a multiplet of states with spin values in the range $[[j_n - 2], j_n + 2]$ at an

On the other hand, the energies of the $N = 52$ and $N = 48$ isotones [Fig. 4(a)] are two times smaller than those of their $N = 50$ cores. Moreover, the quadrupole energy in the $N = 48$ isotones has a minimum at $Z = 32$ – 34 , indicating that the quadrupole deformation is maximum at midproton shell. This hypothesis is corroborated by the fact that the $E(4_1^+)/E(2_1^+)$ ratio reaches its maximum value there, ~ 2.7 , which is intermediate between vibrator and rotor nuclei [see the inset of Fig. 4(b)]. Thus extra binding energy due to correlations depresses to a larger extent the atomic mass of the ground state of $N = 48$ isotones at the mid proton-shell, giving rise to the observed increase of $BE_{2n}(50)$. The same mechanism has been recently discussed for isotopes with $N \sim 90$ (see Section 3 of Ref. [15]).

As for the $N = 52$ isotones, their quadrupole energy decreases slowly [see Fig. 4(a)]. Even though their low 2_1^+ energies are not far from those of the $N = 48$ isotones, their quadrupole collectivity is different as demonstrated by the fact that the $E(4_1^+)/E(2_1^+)$ ratios remain almost constant and close to 2, that is the vibrational limit. Since the collective behavior of the $N = 52$ isotones does not vary significantly with Z , the extra binding energy depresses equally all the ground state masses, thus explaining why the evolution of $BE_{2n}(52)$ remains quasilinear. One may assume that the extra binding is not the same for the even- Z and odd- Z isotones, leading to the two straight lines observed in Fig. 3.

In summary, the quadrupole characters associated to the low-energy states of the $N = 48$ and $N = 52$ isotones add correlation energies to the BE_{2n} values, which could therefore not be used to determine the evolution of the spherical orbits bounding the $N = 50$ gap. Such a statement had been already put on a firm theoretical basis in several regions of the nuclear chart for which static deformation and dynamic fluctuations around the mean-field ground states have proven to modify the atomic masses and apparent shell gaps (see for instance, Ref. [16], and references therein). To reduce the amount of correlations in the determination of shell gaps, we propose to use the binding energy of the 8^+ isomer of the $N = 48$ isotones instead of the one of their ground state.

IV. EVOLUTION OF THE $N = 50$ GAP USING THE 8^+ ISOMERIC STATE

Isomeric 8^+ states have been found around 3 MeV in all the $N = 48$ isotones. Their configuration was assigned to $(\nu g_{9/2})^{-2}$ in which the two holes couple to the maximum spin value $J = 8$ in a spherical configuration (see Ref. [13], and references therein). The isomerism is due to the relatively small energy between the 8_1^+ and 6_1^+ states. Such a small energy difference implies that the 8^+ isomers cannot belong to a vibrational/rotational band, and are well separated in

energy close to the 2_1^+ excitation of the core: This is well established in some of the $N = 51(49)$ isotones (see Refs. [13,14], and references therein).

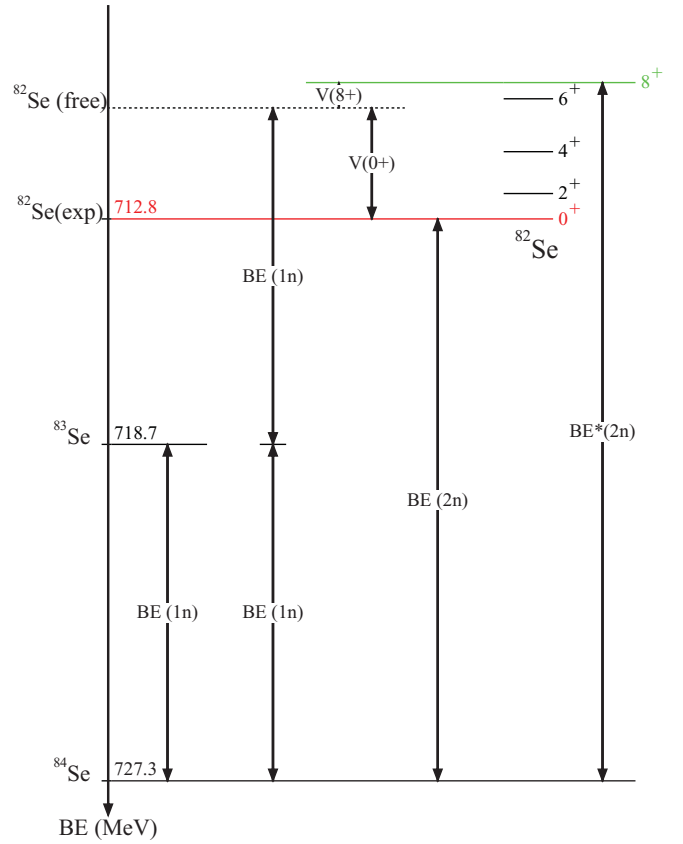


FIG. 5. (Color online) Pictorial illustration of the total binding energies, BE, and various neutron binding energies, BE_{1n} , $2BE_{1n}$, BE_{2n} , and BE_{2n}^* for the Se isotopes, showing the correlation energy of the $0_{g.s.}^+$ state, $V(0^+)$, and the residual interaction of the 8^+ spherical state, $V(8^+)$, in $^{82}\text{Se}_{48}$.

energy from any 8^+ ‘collective’ state. It follows that the configuration of these 8^+ isomers is assumed to be rather pure, contrary to that of the ground state. The binding energy of such a spherical state, being directly related to the one of the orbit, gives another mean to characterize the evolution of the $\nu g_{9/2}$ energy as a function of the proton number.

For this purpose, we define another binding energy of the last two neutrons of the $N = 50$ isotones, $BE_{2n}^*(50)$, using the total binding energies (BE) of the nuclei of interest and the excitation energy of the 8^+ isomeric states:

$$BE_{2n}^*(Z, 50) = -[BE_{g.s.}(Z, 50) - BE_{8^+}(Z, 48)] \\ \equiv [BE_{g.s.}(Z, 48) - E_{\text{exc}}(8^+)] - BE_{g.s.}(Z, 50) \quad (1)$$

The meaning of the neutron binding energies, BE_{1n} , $2BE_{1n}$, BE_{2n} , and BE_{2n}^* , is given in Fig. 5 for the $^{82,83,84}\text{Se}$ isotopes.

The evolution of the BE_{2n}^* values as a function of Z is drawn in Fig. 6. Noteworthy is the fact that the change of slope in $BE_{2n}(50)$ observed at $Z = 32$ in Fig. 3 has disappeared. The BE_{2n}^* values rather display a straight line with a slope

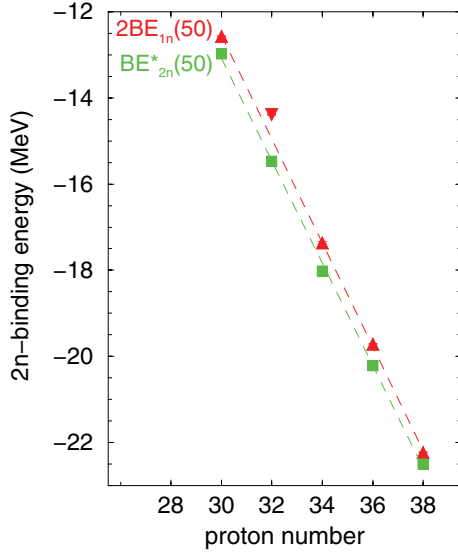


FIG. 6. (Color online) Experimental binding energies of the two last neutrons in $N = 50$ isotones: Values of $2BE_{1n}(50)$ (red triangles, cf. Fig. 2) and of $BE_{2n}^*(50)$ [green squares, cf. Eq. (1)]. The difference between the two lines is, by definition, the interaction energy between the two neutrons located in the $\nu g_{9/2}$ orbit, which couple to $J = 8^+$. The uncertainties are smaller than the symbols.

of $-1.19(2)$ MeV/proton. This slope matches the one of $-1.20(1)$ MeV/proton obtained using the $2BE_{1n}$ values. We therefore deduce that a large part of the deviation of $BE_{2n}(50)$ to a straight line originates from the correlation energy of the ground state of the $N = 48$ isotones, labeled as $V(0^+)$ in Fig. 5. Indeed the relative distance in energy between the 0_{gs}^+ and 8_1^+ states for the $N = 48$ isotones is maximum at $Z \simeq 32, 34$ as shown in Fig. 7.

In summary, the approaches using BE_{1n} and BE_{2n}^* give similar results with respect to the behavior of the $\nu g_{9/2}$ orbit as a function of the occupation of the $\pi f_{5/2}$ and $\pi p_{3/2}$ orbits. As these two approaches do not strictly use the same experimental data (only the atomic masses of the $N = 50$ cores are in common), we have more confidence in the linear fits proposed in Sec. II.

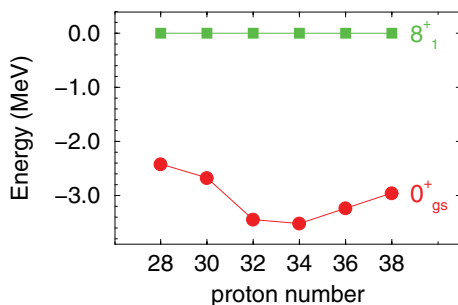


FIG. 7. (Color online) Distance in energy between the 0_{gs}^+ and the 8_1^+ states for the $N = 48$ isotones as a function of the proton number. The energies of the 8_1^+ state are fixed to 0.

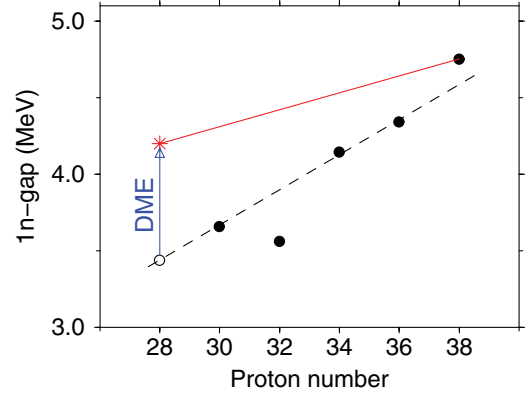


FIG. 8. (Color online) Difference of the binding energies of the two states surrounding the gap at $N = 50$ [cf. Fig. 2(b)]. When using the averaged DME value of ^{48}Ca (see text), the $N = 50$ gap would amount to 4.2 MeV for $Z = 28$. The solid line gives the evolution of the $N = 50$ gap from $Z = 28$ to $Z = 38$.

V. DISCUSSION

The structure of the neutron-rich nucleus ^{78}Ni , having $Z = 28$ and $N = 50$ magic numbers, depends on the size of the $N = 50$ and $Z = 28$ spherical gaps and on the amount of the quadrupole correlations provided by generating excitations across them.⁴ In this section, we discuss the behaviors of the two gaps in order to argue about the doubly magic nature of ^{78}Ni .

In Sec. II, we gave the extrapolation of the $N = 50$ correlated gap at $Z = 28$, 3.44 MeV, and the reduction of correlation energy due to the $Z = 38$ shell closure, which amounts to 0.17 MeV. Nevertheless, a much larger singularity may occur in a nucleon shell gap when the number of nucleons of the other species is equal to a magic number, the so-called “doubly magic effect” (DME). Besides the well-known cases dealing with the Wigner term which gives an additional binding to nuclei having $N = Z$, there are a few other cases which are shown in several figures of Ref. [5]. For instance, the $Z = 20$ gap is enhanced by 0.86 MeV at $N = 28$ (see the Fig. 17 of Ref. [5]) and the $N = 28$ gap is enhanced by 0.71 MeV at $Z = 20$ (see the Fig. 20 of Ref. [5]), that gives an averaged DME value of 0.78 MeV. If the odd- N nuclei close to $^{78}\text{Ni}_{50}$ behaves as odd- A nuclei close to ^{48}Ca , the value of the $N = 50$ spherical gap for $Z = 28$ would be 4.2 MeV, as shown in Fig. 8.

The $Z = 28$ spherical gap is reduced when going toward $N = 50$. This has been demonstrated by the monopole migration of the $\pi f_{5/2}$ orbit as the $\nu g_{9/2}$ is filled [17], provoking an inversion between the $\pi p_{3/2}$ and $\pi f_{5/2}$ in the ^{29}Cu chain at $A = 75$ [18]. More indirectly, the $B(E2; 0^+ \rightarrow 2_1^+)$ excitation strengths measured in two neutron-rich ^{28}Ni isotopes [19,20] can be reproduced only when invoking an increasing amount of proton core excitations from the $\pi f_{7/2}$

⁴Quadrupole correlations across the $N = 50$ and $Z = 28$ spherical gaps may be strongly favored since the two orbits bounding both of them have $\Delta l = 2$: $\pi f_{7/2}$ and $\pi p_{3/2}$ on the one hand, $\nu g_{9/2}$ and $\nu d_{5/2}$ on the other hand.

orbital to the other πfp orbits. In addition, the rapid lowering of the first $1/2^-$ state in $^{69-75}\text{Cu}$ and the enhancement of the $B(E2; 1/2^- \rightarrow 3/2^-)$ transition rates provide other proofs of the major role of the $\pi f_{7/2}$ orbital in the description of the $Z \geq 28$ isotopes [21]. Moreover, the SM calculations of Ref. [21] indicate that the $Z = 28$ shell closure gets reduced by about 0.7 MeV between ^{68}Ni and ^{78}Ni .

Theoretical models predict $^{78}_{28}\text{Ni}_{50}$ to be a doubly-magic spherical nucleus (see, for instance, Refs. [22,23]). Using the present empirical findings, one can only argue on qualitative statements upon its magicity. The two magic numbers, 28 and 50, are created mainly by the spin-orbit interaction and $^{78}_{28}\text{Ni}_{50}$ belongs to the same family of other doubly spin-orbit nuclei as $^{20}_6\text{C}_{14}$, $^{42}_{14}\text{Si}_{28}$, and $^{132}_{50}\text{Sn}_{82}$. The latter has the major characteristics of a doubly magic spherical nucleus [25,26] while the two others have not [3,24]. The first excited state of $^{42}_{14}\text{Si}_{28}$ measured at very low energy is due to the erosion of both the $Z = 14$ and $N = 28$ shell closures (caused by action of the mutual proton and neutron forces) and to the quadrupole correlations between states bounding the two gaps [3]. Such a deformed configuration could be found for the ground state of ^{78}Ni or a low-lying state. Under this latter assumption a shape coexistence could be found for ^{78}Ni , as it has been recently observed at the $N = 28$ shell for $^{44}_{16}\text{S}_{28}$ [27].

VI. SUMMARY

The evolution of the $N = 50$ gap between $Z = 30$ and $Z = 38$ has been studied by means of three different methods

based on one or two-neutron separation energies of ground or isomeric states, which all take into account the newly determined atomic masses of Refs. [6,7]. By extracting the $N = 50$ gap from these methods, different degrees of correlations are intrinsically involved. These correlations distort the extracted gap value, which is rather than a correlated one. The correlations are the strongest at $Z = 32$, and weakest at the two proton shell closures $Z = 38$ and $Z = 28$. It has been shown that the use of two-neutron separation energies to analyze the evolution of the $N = 50$ gap value is the most subject to correlations provided in particular by the $N = 48$ nuclei. This is partly remedied by using atomic masses of the least correlated 8^+ isomeric state of the $N = 48$ nuclei, rather than those of the $N = 48$ ground states. Gathering the results of the three methods, we propose a global reduction of the $N = 50$ gap between $Z = 38$ and $Z = 28$ by about 0.55 MeV, which is to combine to the expected reduction of the $Z = 28$ gap at $N = 50$. It follows that the structure of the ^{78}Ni nucleus is probably intermediate between the deformed ^{42}Si and the spherical ^{132}Sn . Whether ^{78}Ni would be deformed, spherical or exhibit a shape coexistence depends on a delicate balance between the size of the $Z = 28$ and $N = 50$ spherical gaps which preserve its sphericity, and the amount of correlations brought by promoting nucleons across these gaps leading to deformation.

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